

THE EUTROPHICATION POTENTIAL
OF NITRATES
IN THE
SERPENT RIVER SYSTEM
OF NORTHEASTERN ONTARIO

December, 1985



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IN THE SERPENT RIVER SYSTEM
OF NORTHEASTERN ONTARIO

by: G. Myslik

December, 1985

NORTHEASTERN REGION

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SUMMARY AND CONCLUSIONS

Nitrates are present in the Serpent River System as a result of their use in explosives, in the uranium recovery process and as oxidation products of ammonia released during mining and milling activities.

On a recommendation of the Environmental Assessment Board Report (1979) into the expansion of uranium mining activity in the Serpent River Basin, a study was undertaken to investigate the potential of high aquatic nitrate concentrations to promote eutrophication.

A section of the Serpent River System having sources of both nitrogen and phosphorus was chosen for this study since it is known that phosphorus, under certain conditions, can be the limiting nutrient in regulating biological activity.

The evaluation of biological trophic status indicators, along with water chemistry parameters, within the lakes of the Western Arm of the Serpent River System revealed that high nitrogen concentrations, by themselves, did not lead to signs of biological enrichment. Where phosphorus from sewage treatment effluents was also present, the expected higher degree of biological activity was measured.

Because the presence of high concentrations of nitrates in the Serpent River System does not in itself promote eutrophication but relies heavily on a supply of phosphorus, the control of nitrates in the management of trophic status is not a necessary consideration.

The commissioning of a 18,200 m³/day sewage treatment plant and diversion of its discharge to a waterbody with a source of industry-related nitrates had the potential to promote trophic enrichment in downstream lakes.

The potential effects of phosphorus loading from the new sewage treatment plant were evaluated by empirical modeling. The models predicted that the additional phosphorus would

be quickly assimilated through the study lakes. It is unlikely that phosphorus additions would reach the Serpent Harbour and lead to local eutrophication.

INTRODUCTION

HISTORY

The uranium mining industry in Ontario began in 1953 with the discovery of a large ore body in the Serpent River basin. In 1957 eleven mines were operating in the Elliot Lake area to supply an expanding market demand. Following the initial boom, falling world demand for uranium reduced the number of operating mines to five by 1966 with a further reduction to two mines by 1972.

The environmental effects of the uranium mining-milling industry on the Serpent River basin were investigated by the Ontario Water Resources Commission between 1966 and 1969 and reported in a document entitled "Water Pollution from the Uranium Mining Industry in the Elliot Lake and Bancroft Areas (1972)". Water quality problems identified within the Serpent River System included: depression of pH, the presence of high and potentially toxic concentrations of ammonia, and increases in dissolved solids and sulphate concentrations.

The demand for uranium rose in 1974 and generated renewed activity in the Elliot Lake area.

In order that industrial expansion proceed in an environmentally acceptable manner, a Provincial Order-In-Council, September 22, 1976, directed the Environmental Assessment Board to evaluate the potential effects of the expansion on the quality of the environment.

One of the subjects addressed was the possibility that the presence of elevated nitrate/ammonia concentrations in the

Serpent River System could promote eutrophication.

The findings of the Environmental Assessment Board were released in May 1979. The following excerpts were included in the Findings and Recommendations of the Board.

- 11-5 The Board finds that because phosphorus levels are low and phosphorus is a limiting nutrient, the evidence does not support the contention that nitrates in the Serpent River System are presently a problem. However the Board is concerned with nitrate loadings that might reach the Serpent Harbour and at some future date because of phosphorus additions lead to local eutrophication.
- 11-6 The Board recommends that the Province design and implement an experiment/study to determine whether nitrate loadings in the Elliot Lake area can lead to eutrophication and to see whether a nitrate reduction program in the operating mills is necessary.

In the Provincial government's response to the final report of the Environmental Assessment Board (1981) there was agreement with the Board's findings on phosphorus. The Board's concern regarding the possible impact of nitrates downstream of the mills was also noted and a commitment was made to undertake a study investigating the eutrophication potential of nitrates in the Serpent River System.

NITRATE SOURCES

Eutrophication, from an ecosystem point of view, is broadly defined as nutrient or organic enrichment or both, that results in high primary biological activity and an array of symptomatic changes leading to undesirable changes in water

quality. Eutrophication is promoted by the access of nutrients to natural aquatic systems; in particular, the nutrients phosphorus and nitrogen. Of these, the nutrient nitrogen can be incorporated by aquatic plant life in either its ammonia or nitrate forms. The natural interconvertibility of ammonia and nitrate in the aquatic environment requires that both these forms of nitrogen be considered when potential for eutrophication is studied.

Environmental concentrations of ammonia are typically less than 0.1 mg/L while concentrations of nitrate are often less than 1 mg/L (Water Quality Sourcebook 1979). In the Precambrian Shield area of Ontario average nitrate concentrations in natural aquatic systems are generally below 0.2 mg/L Ministry of the Environment (MOE 1978). Higher concentrations are usually indicative of anthropogenic inputs.

Natural sources of ammonia include atmospheric precipitation, dry fallout, decomposition of nitrogenous organic matter or the microbial reduction of nitrates or nitrites under anaerobic conditions.

Nitrates are present in rainwater and can be contributed from the weathering of rocks. The complete oxidation of organic materials is also a nitrate source.

In the Serpent River System nitrates and ammonia are introduced through the processes and waste disposal practices of the mining-milling operations in the basin. Sources include:

(a) the use of explosives containing high nitrate and ammonia

components

- (b) the use of a nitrate elution-ammonia precipitation process in milling of uranium ore (N.E.A.P.)

NITRATES AND EUTROPHICATION

The influence of nitrates in eutrophication has been a focus of investigation for many years. Research projects have fallen into three broad often intermingled categories of endeavour.

- (a) Observational studies of natural systems

Early observational work involved the investigation of natural aquatic systems whose nutrient sources had been modified by the input or diversion of treated sewage inflows.

In Lake Tahoe, nitrogen and the trace element iron were identified as the major limiting factors for phytoplankton growth. The utilization of phosphorus was found to be dependent on the availability of nitrogen. Algae culture experiments with Lake Tahoe water produced increased growth from additions of nitrate as low as 5 and 20 $\mu\text{g}/\text{L}$ (Goldman 1972).

In Lake Washington, it was determined that the effectiveness of the phosphorus supply in promoting algal growth was affected by the presence of nitrates (Edmondson 1972). The use of Lake Washington water in enrichment experiments produced varying results to the addition of the nutrients phosphorus and nitrogen. Small increases in algal activity

were generally observed with the separate addition of either P or N. When both nutrients were added in combination, large growth stimulation resulted. Edmondson(1968) also speculated about the possible effects of enrichment of natural lake waters with a rich solution of nitrate such as tertiary sewage effluent deprived of phosphorus. He felt that some species of algae might be encouraged to grow massively using the normal small amounts of available phosphorus.

The classic work on nutrient loading and eutrophication applicable to wide ranges of trophic status was published by Vollenweider (1968). A system was described which allowed classification of lakes into three categories of trophic status based on separate loadings of nitrogen or phosphorus. The relationship of trophic status and nitrogen assumed an N/P ratio of 15:1 by weight, the important point being that nitrates were considered main components in the process of eutrophication.

Jaworski et al (1972) in a summary paper of water quality studies on the hypereutrophic Potomac estuary, described nuisance levels of rooted aquatic plants and recurring blue green algae blooms associated with large phosphorus and nitrogen loadings. Nitrogen was cited as a major factor limiting algal growth in sections of the estuary. Increases in nitrogen led to increases in heterotrophic activity which in turn stimulated algae growth. Bioassay studies to determine which nutrients were limiting algal growth also indicated that stretches of the Potomac were becoming nitrogen limited. The standing crop of nuisance blue-green algae was controlled by the availability of nitrogen. An upper limit of 0.3 mg/L nitrogen was proposed to control nuisance algae blooms.

Kappers (1980) investigating growth limiting factors in Lake Brielle, noted that phosphorus was not always a growth limiting factor in lakes with excess phosphorus supplies. Algal biomass in hypereutrophic lakes was often regulated by nitrogen availability.

In meso-oligotrophic Grasmere Lake the addition of nitrogen-rich sewage effluent did not result in a nitrogen regulated plankton population. Here inorganic nitrogen was considered to be of secondary importance in the control of algal growth (Hall et al 1978).

b) Laboratory and Small-scale In-situ Assays

The algal assay has been found to be a valuable tool in evaluating water quality particularly in relation to eutrophication. The designs of algal assay experiments have been improvised to meet specific research needs; but overall they have functioned to:

- a) identify algal growth regulating nutrients
- b) determine the availability of growth promoting or limiting nutrients
- c) quantify biological responses to changes in concentrations of algal growth limiting nutrients.

The influence on algal growth of nitrogen by itself and in combination with phosphorus has been demonstrated in numerous laboratory algal assay experiments.

Fuhs et al (1972) in bioassay experiments on the waters of Lake George, New York concluded that multiple nutrient limitation affected algal biomass. At times, nitrogen limitation was an important factor.

Algal assays conducted on waters from nine Oregon lakes of varying water quality showed that the addition of nitrogen alone only slightly stimulated the growth rates of algae in two of the lakes. When phosphorus and nitrogen were added in combination, algal growth rates were stimulated in most of the lake waters. While phosphorus was initially limiting for algae growth, nitrogen became limiting when sufficient phosphorus was present (Maloney et al 1972).

Weiss (1976) investigating the relationship of algal assay results and the trophic status of 44 waterbodies in North Carolina with varying concentrations of inorganic nitrogen (56 mg/m^3 - 1245 mg/m^3), found that many of the waters investigated were limited by nitrogen when phosphorus concentrations were relatively high and the N:P ratio was less than 10. In addition, a significant number of lakes were also limited by a phosphorus-nitrogen combination approximately equal to 10:1. The consistent pattern of the ratio of soluble nitrogen and phosphorus components to the indicated limitation of either one, the other or both of the algal nutrients suggested that the ratio could be used to define the limiting nutrient.

Miller, Green and Shiroyama (1976) investigating the effects of wastewater input to the Snake and Palouse Rivers found stimulation of algal growth by inorganic nitrogen when the N:P ratios were less than 11.3:1. They concluded that waters containing N:P ratios less than 10 may be considered nitrogen

limiting while those with phosphorus limitations had N:P ratios greater than 10.

In-situ experiments of algal response to various nutrient additions were carried out by Powers et al (1972) on lakes of varying productivity in Minnesota and Oregon. Stimulatory growth response was obtained in the mesotrophic Burntside River only when phosphorus and nitrogen were added in combination. For the eutrophic Shagawa Lake, positive in-situ growth response resulted from additions of nitrogen, phosphorus and both nutrients combined. Oligotrophic Waldo Lake in Oregon did not respond to additions of nitrogen alone but algal growth was stimulated by combinations of N and P.

The enclosure of natural phytoplankton assemblages in large plastic bags within Lake Michigan (Schelske and Stoermer 1972) and the addition of different combinations of N:P:Si resulted in growth stimulation in combined nutrient addition treatments. Phosphorus was considered to be the limiting nutrient. Nitrogen was not a significant factor. Subsequent work studying the effects of N and P enrichments on natural phytoplankton assemblages from Grand Traverse Bay, Lake Michigan revealed that increases in major nutrients to oligotrophic systems resulted in dramatic increases in productivity. Phosphorus was the main limiting nutrient eliciting largest responses between concentration ranges of 5 and 15 ug/L while nitrogen by itself had no significant enrichment effect (Stoermer et al 1978).

c) In-situ Whole Lake or Major Basin Experiment

The most definitive investigations into the effects of nutrient additions to natural lake systems were the whole lake fertilization experiments conducted in the Experimental Lakes Area of Northwestern Ontario.

Lake 227, a small oligotrophic lake characterized by low concentrations of dissolved inorganic carbon was fertilized with phosphate and nitrate over a four year period. The rate of nutrient application was approximately five times that of natural input. Large standing crops of phytoplankton were produced by additions of both phosphorus and nitrogen. Species dominance shifts from Chlorophyta to Cyanophyta were documented. Additions of the nutrient elements singly revealed that phosphorus always caused some increase in algal standing crop, while addition of nitrogen alone never elicited a response. (Schindler et al 1973).

Schindler and Fee (1974), and Schindler (1975) described a continuing series of whole lake experiments in eutrophication.

Lake 227 continued to respond to the addition of nitrogen and phosphorus by supporting high standing crops of phytoplankton. Carbon, although naturally in short supply, was not a limiting factor in phytoplankton production as CO₂ invading from the atmosphere supplied most of the carbon necessary to support increased production from the addition of N and P.

Lake 304 was fertilized with phosphorus, nitrogen and carbon in 1971 and 1972, increasing average epilimnetic chlorophyll concentrations from 4 ug/L to the 20-30 ug/L range. In 1973 phosphorus additions were curtailed while nitrogen and carbon additions were continued. Chlorophyll concentrations returned almost to pretreatment levels the first year that phosphorus additions were discontinued. Algal species composition also returned to pretreatment type. The continued high

input of nitrogen and carbon did not promote excessive algal growths in the presence of small amounts of phosphorus.

Lake 226 was characterized by two nearly identical basins connected by a narrow channel. The lake was divided in half by a vinyl impregnated nylon curtain in 1973. Its western basin was loaded with nitrogen and carbon while phosphorus, nitrogen and carbon were added to the eastern basin. The eastern basin had blooms of diatoms and blue-green algae while phytoplankton in the basin with nitrogen addition only remained at prefertilization levels. When nitrogen deficiencies occurred in the eastern basin, they were partially overcome by the activities of nitrogen fixing blue-green algae allowing utilization of available phosphorus.

Lake 302, a twin basin lake, was loaded with phosphorus, nitrogen and carbon in quantities shown to eutrophy Lake 227; however, nutrient additions were made to the hypolimnetic waters of one basin only. No algae blooms were recorded in the epilimnetic waters. Neither could a shift in species composition be detected. It was found that the added fertilizer was rapidly taken up by hypolimnetic suspended matter and sedimented. An algal growth pulse was recorded during autumn turnover but, it was small when compared to the lakes treated with epilimnetic fertilizer additions. Sediment-water interactions were identified as extremely important processes in the removal of nutrients. There was little return of phosphorus from the sediments to the water column.

One of the conclusions arising from the early eutrophication experiments was that while lakes responded to inputs of phosphorus and nitrogen by increased algal biomass and

production, the magnitude of the response could be controlled by regulating the phosphorus input alone.

A measured effect of loading the nutrients phosphorus and nitrogen to the experimental lakes has been the modification in the species composition of the phytoplankton communities whether epilimnetic or hypolimnetic loadings occurred (Findlay 1978, Fee 1979). The ratio of N:P was important in regulating the dominance of algal groups. High N:P ratios favoured chlorophyte dominance while loading of nitrogen amounts that were small relative to the phosphorus loads, favoured the development of Cyanophycean blooms.

Smith (1982) reviewed the nitrogen and phosphorus dependence of algal biomass in lakes and found that nitrogen can significantly modify a lake's biological response to phosphorus. He concluded that the nitrogen to phosphorus ratio provides a source of variability in the phosphorus- chlorophyll relationship. The concentration of nitrogen influences the concentration of chlorophyll even in lakes where phosphorus alone has previously been presumed to be limiting (N:P greater than 10-17). Data on 12 north temperate lakes revealed shifts from blue-green to green algae and diatoms as the N:P ratio in the lakes increased. The effects of the N:P ratio on algal biomass appeared to be driven by species shifts in the phytoplankton.

In summary, a review of scientific literature into the influence of nitrogen (nitrate, ammonia) in the process of eutrophication has shown that this nutrient is an important factor. Observations on natural systems, the results of

laboratory and in-situ algal assays and whole lake fertilization experiments have shown that:

- a) phosphorus in the majority of cases is the main nutrient limiting algal biomass and growth,
- b) phosphorus limitation decreases as the trophic status of lake water increases,
- c) nitrogen can be the main limiting factor when sufficient phosphorus is available to sustain algal growth,
- d) the ratio of N:P must be greater than 10:1 for phosphorus to be limiting and less than 10:1 for nitrogen to be limiting,
- e) nitrogen by itself is not a eutrophying agent,
- f) the addition of nitrogen in combination with phosphorus stimulates algal growth and biomass production,
- g) nitrogen is a controlling factor in the stimulation of phytoplankton growth when phosphorus is also present,
- h) the nitrogen to phosphorus ratio has a role in the determination of phytoplankton species composition.

Based on the conclusions and recommendations of the Environmental Assessment Board and the historical information regarding the potential of nitrogen as a eutrophication agent, an experimental design was required that would determine the influence of the nitrate/ammonia concentrations in the Serpent River System on eutrophication under various conditions of existing or potential phosphorus availability.

Rapid growth, development and industrial activity in the Town of Elliot Lake coupled with the expansion of municipal services and residential areas, provided the framework for an in-situ evaluation of the nitrate-eutrophication question.

STUDY AREA

The Serpent River Basin is located in northeastern Ontario, covering an area of 1376 km² on the Precambrian Shield. The Serpent River originates north of the Town of Elliot Lake and drains to the North Channel of Lake Huron. Three separate arms comprise the Serpent River System (Figure 1).

The eastern arm of the system begins in the northwestern part of the basin flowing from Dunlop through Stollery to Quirke Lake and then to Kindle, Whiskey and Pecors Lakes.

The central arm of the Serpent River System begins at Crotch Lake and flows through McCabe, May and Hough Lakes before joining the eastern arm at Pecors Lake.

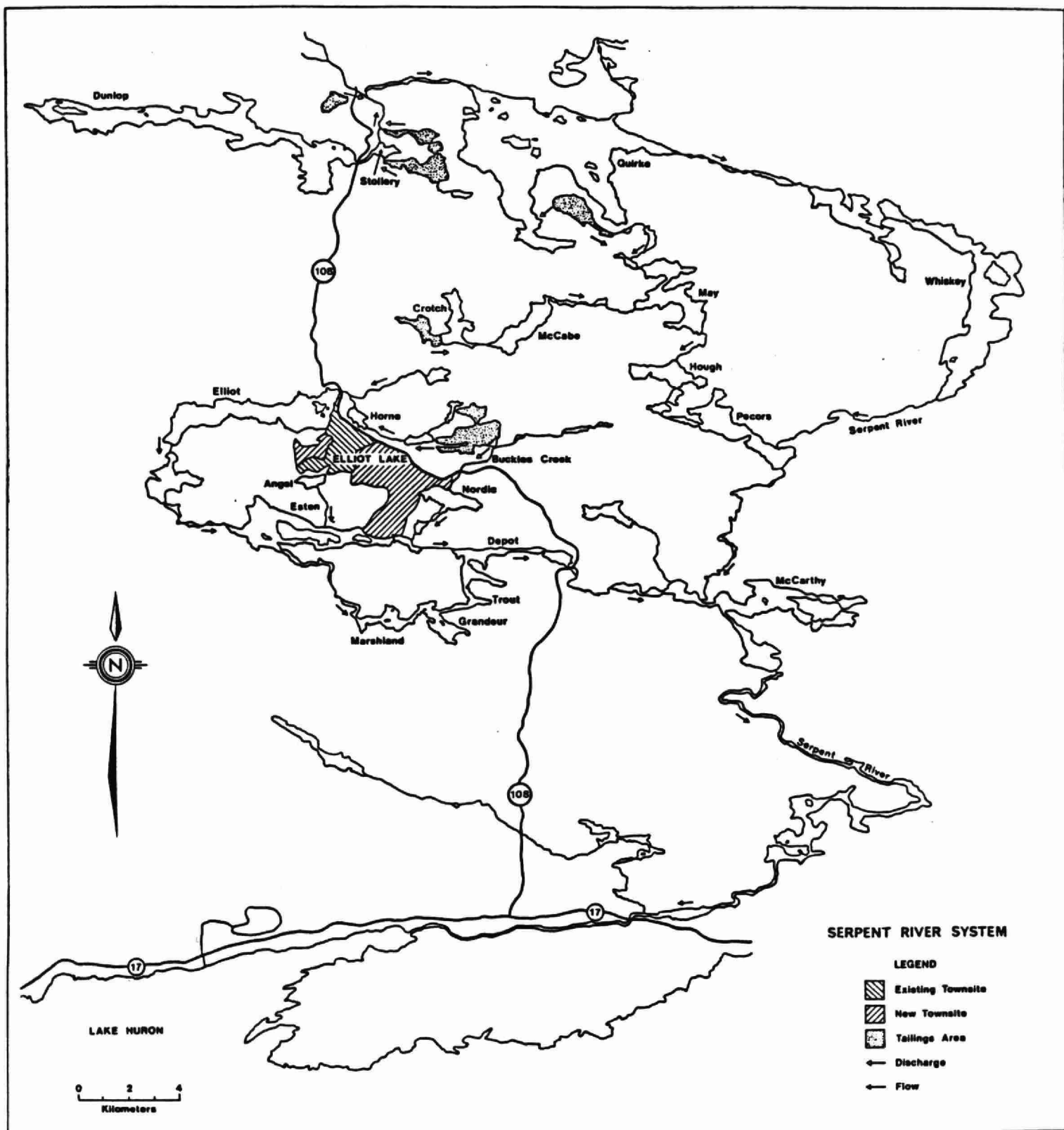
The main part of the western arm of the Serpent River starts at Elliot Lake, proceeds to Esten Lake, flows through Marshland, Grandeur, Trout and Depot Lakes and joins the Serpent River at McCarthy Lake. A minor contributor to the western arm is Buckles Creek which flows to Esten Lake via Nordic Lake and a small unnamed waterbody.

There are six major industrial effluent discharge points to the Serpent River. These include mine-mill water access to:

- i) Stollery Lake
- ii) May Lake
- iii) Quirke Lake via the Upper Serpent River
- iv) Rochester Creek
- v) Crotch Lake
- vi) Buckles Creek

These effluent discharges have resulted in the distributions of nitrate/ammonia shown in Figures 2 and 3.

FIGURE 1



HISTORICAL DISTRIBUTION OF NITRATE/AMMONIA IN THE SERPENT RIVER

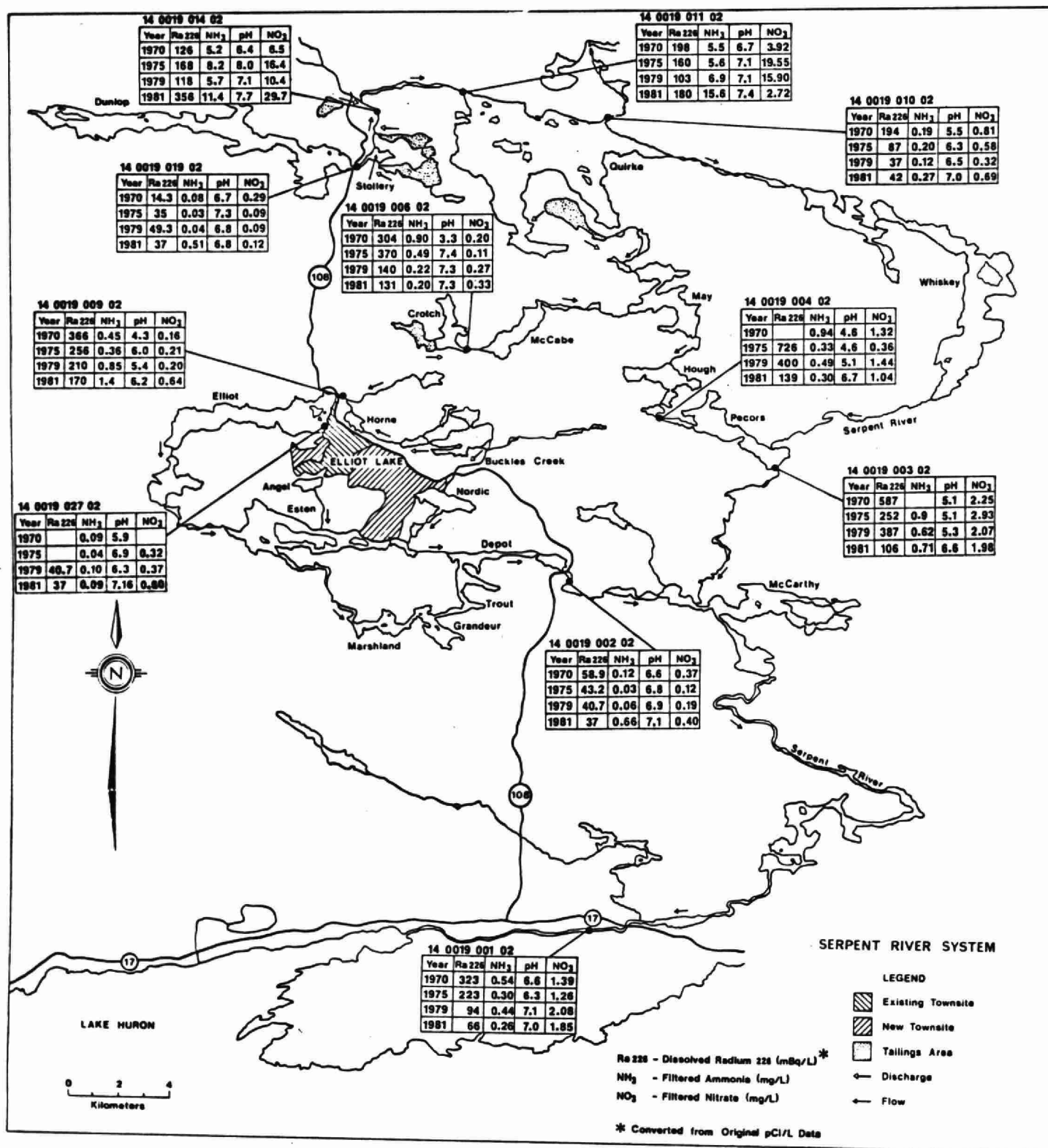
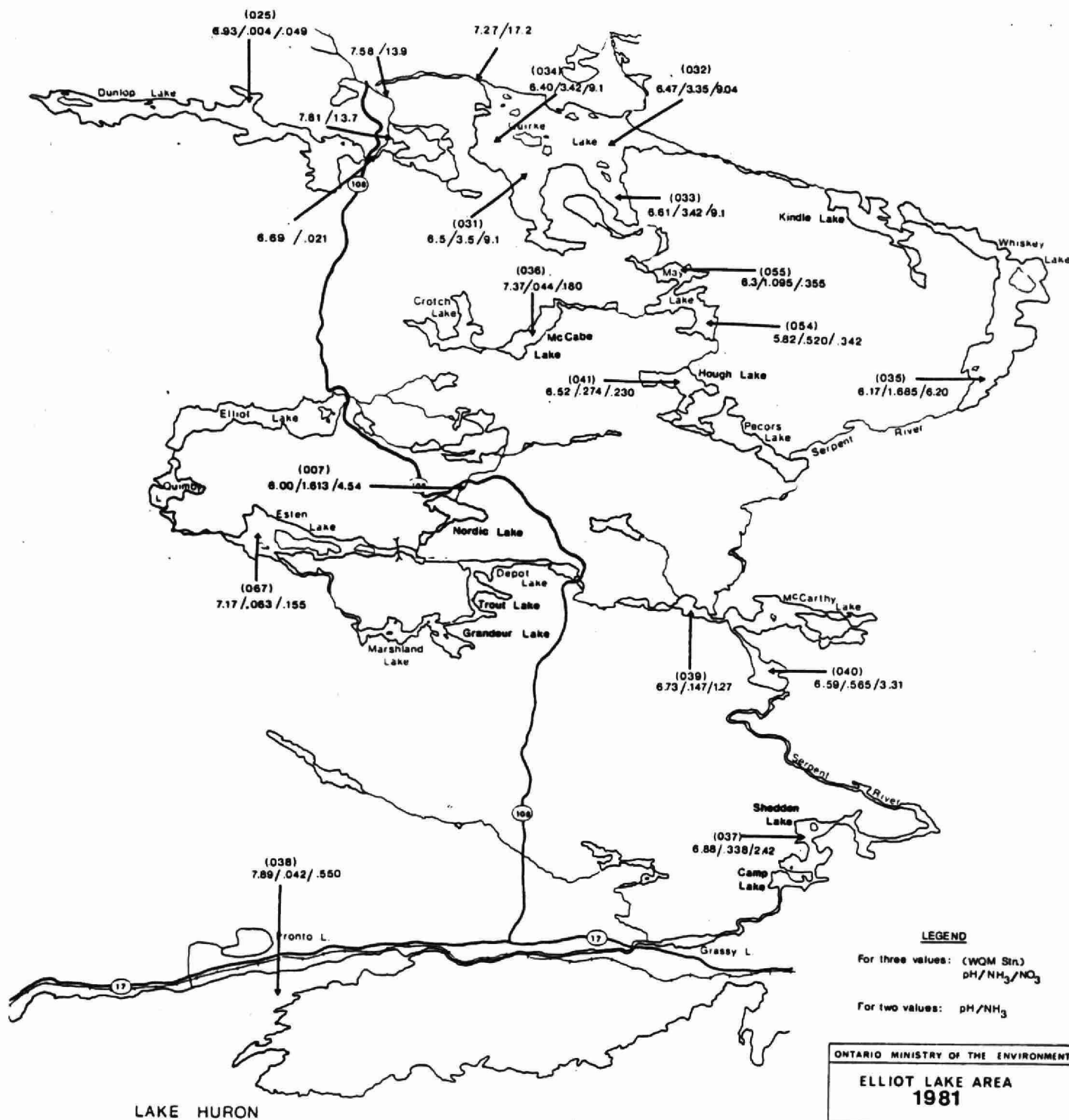


FIGURE 3

DISTRIBUTION OF NITRATE/AMMONIA IN THE SERPENT RIVER - 1981-



The highest concentrations of nitrates and ammonia are recorded through the eastern arm of the Serpent River through McCarthy Lake down to the receiving waters of the North Channel of Lake Huron. However, elevated concentrations of ammonia and nitrates are also present in Buckles Creek which flows to the western arm of the river system.

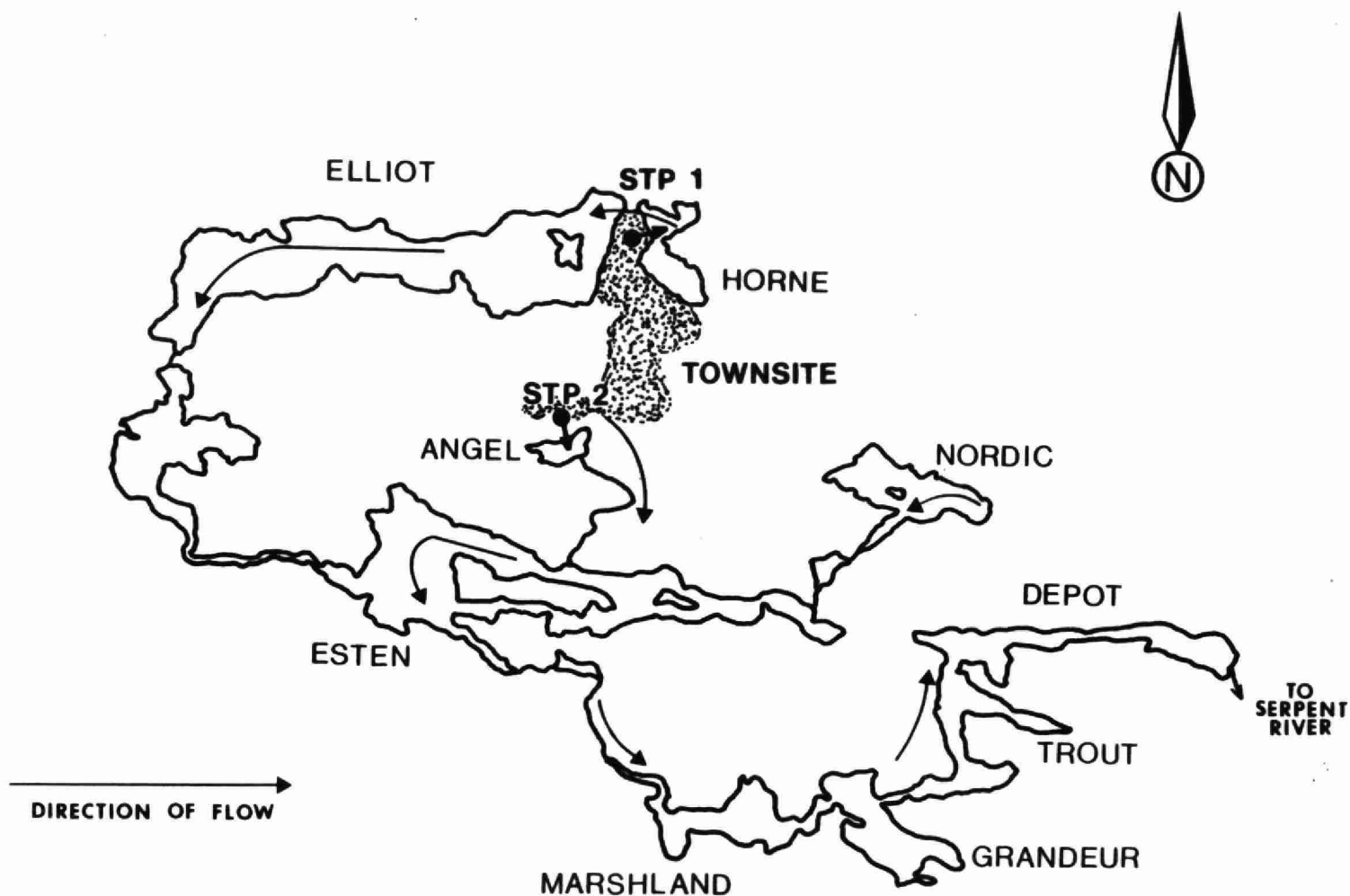
The nitrates and ammonia in Buckles Creek originate from North Nordic Lake which is influenced by 107 hectares of tailings from the non-operational Lacnor and Nordic mines and the ammonium diurate drying and packing operations at the Nordic mine complex.

Anthropogenic phosphorus sources in the Serpent River basin in 1981 were limited to those associated with municipal-based activity in the Town of Elliot Lake. The major inputs of phosphorus to the Serpent River originated at the two sewage treatment plants serving the town. The secondary treatment Horne Lake plant (STP#1) had a design capacity of (1/2 million gallons per day) 2273 m³/day and supplied an estimated 3200 kg/year of phosphorus to Horne Lake which was connected by a stream to Elliot Lake.

The Angel Lake plant (STP#2) had a design capacity of (1 million gallons per day) 4546 m³ and provided primary treatment only. An estimated phosphorus supply of 6,400 kg/yr was discharged to Angel Lake which drained to Esten Lake by means of a small watercourse (Figure 4). In addition, urban runoff from the Elliot Lake townsite supplied phosphorus to the western arm of the Serpent River System via the Elliot and Esten Lake watersheds.

FIGURE 4

NUTRIENT LOADINGS TO THE SERPENT RIVER STUDY AREA



PRE 1981

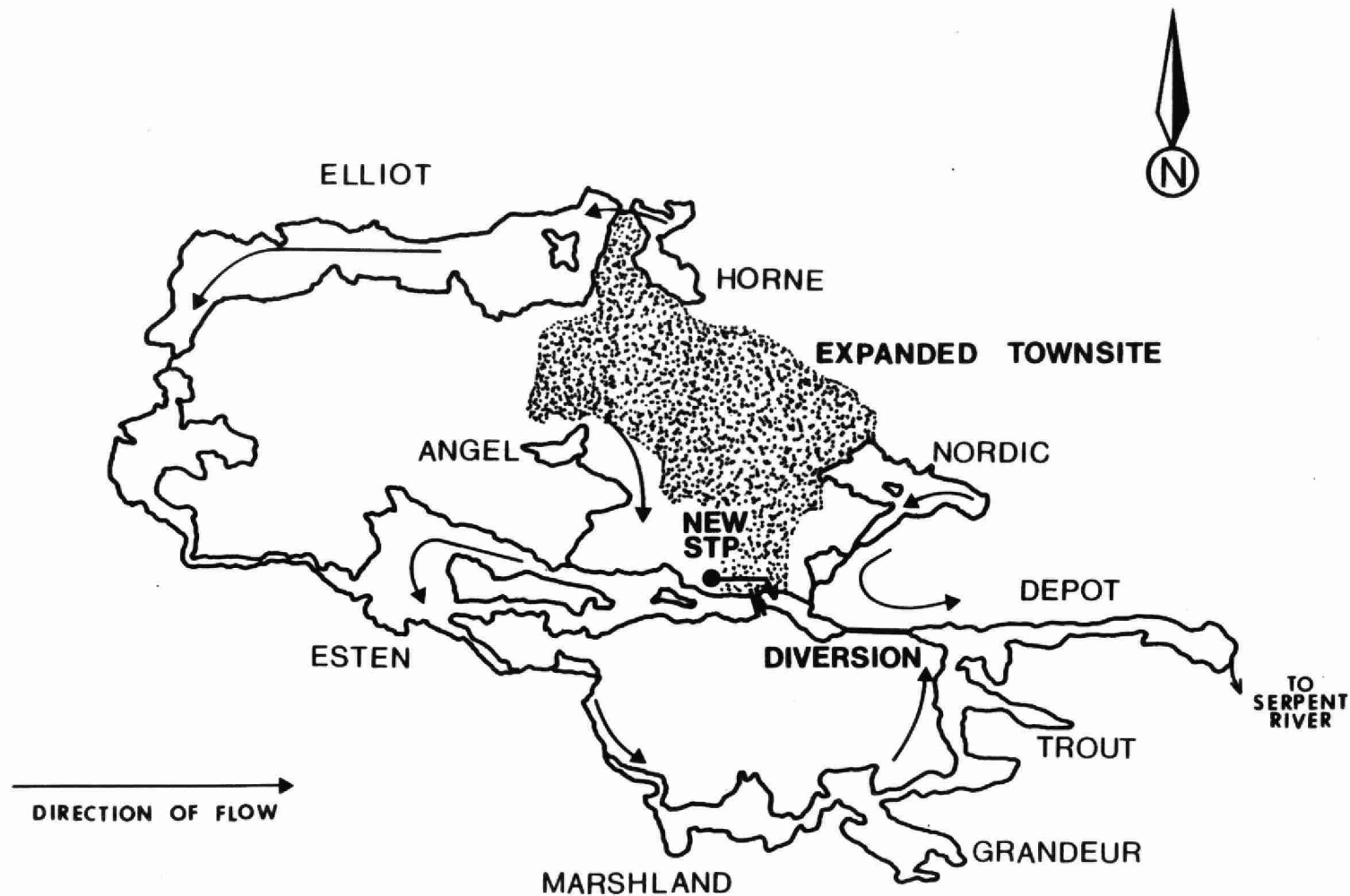
Because the western arm of the Serpent River had contributing sources of nitrates/ammonia, from the Nordic Mine complex, along with phosphorus inputs from sewage treatment plant effluents and urban runoff, it was considered a suitable area in which to evaluate the influence of nitrates as eutrophication agents.

An additional dimension in the selection of the western arm of the Serpent River was the opportunity to document water quality conditions in the system prior to major changes within the watershed to be brought about with the expansion of the town of Elliot Lake and the modernization of local services. Changes to be effected included the two-three fold expansion of the townsite, decommissioning of the two existing sewage treatment plants and consolidation into a new 18,200 m³/day tertiary treatment plant discharging to the eastern end of Esten Lake. The treated sewage effluent flow from the eastern end of Esten Lake and its major inflow, the Buckles Creek- Nordic Lake System were to be diverted to Depot Lake (Figure 5). These changes would result in significant alterations to the nutrient budgets of the lakes in the western arm of the Serpent River.

Because the Nordic-Esten Lake diversion and the commissioning of the new sewage treatment plant were scheduled for December 1981 and the major expansion of the townsite into the Nordic and Esten Lake watersheds was proceeding through 1982-83, it was decided to undertake the field study during the 1981 season. The main purpose of the study was to evaluate the influence of available nitrates/ammonia on the trophic status of lakes in the western arm of the Serpent River. A secondary purpose was to establish a baseline of existing

FIGURE 5

NUTRIENT LOADINGS TO THE SERPENT RIVER STUDY AREA



POST 1981

water quality conditions from which future changes brought about by flow diversions, sewage effluent unloading, new sewage effluent discharges and watershed urbanization, could be gauged.

The influence of nitrates/ammonia on eutrophication in the Serpent River was investigated by studying the water quality and biological conditions of lakes in the western arm of the Serpent River system (Figure 6). The lakes in the system were classified according to the pertinence of information obtained to the study objectives. Sampling frequency and intensity were based on the classification of lakes into A, B and C types.

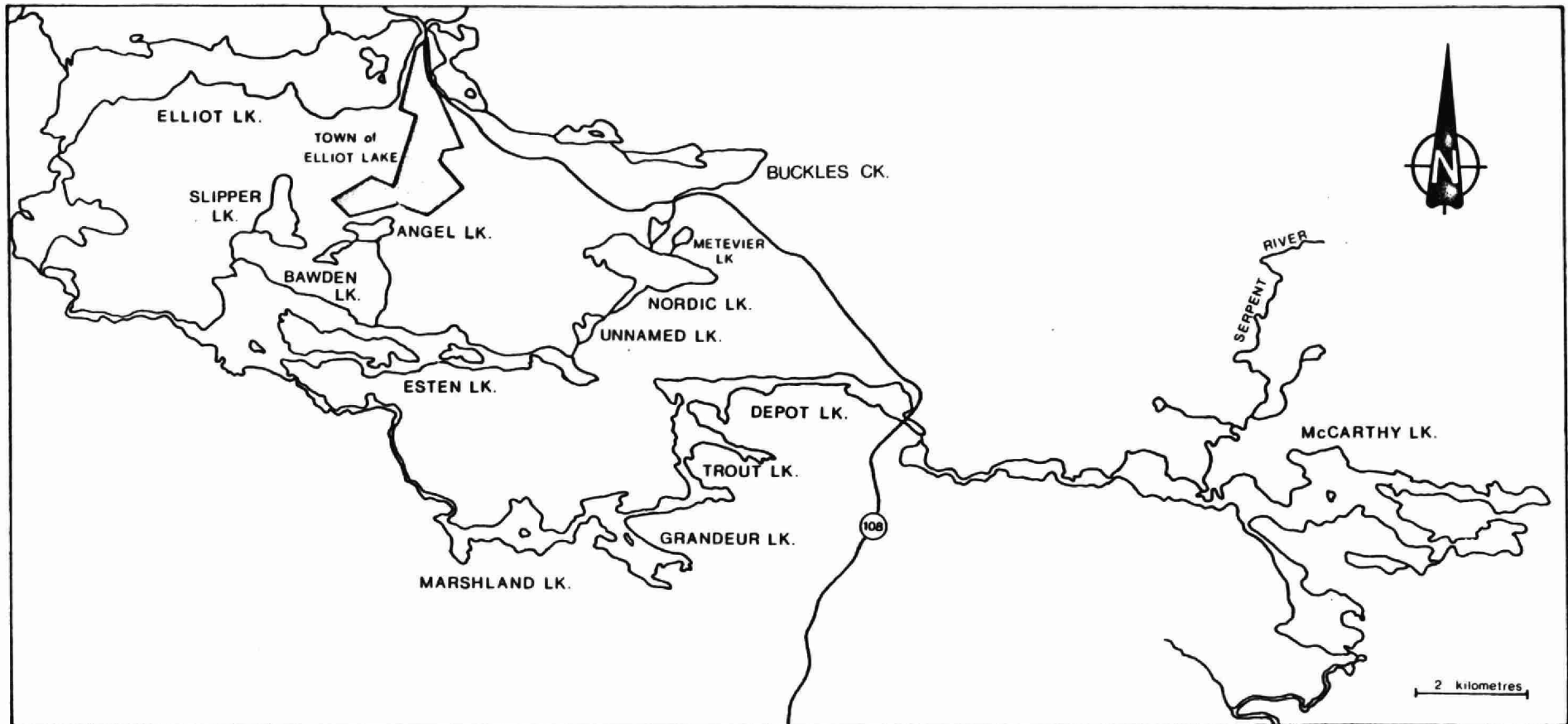
Type A lakes, the most intensely studied, were Nordic, Esten, Depot and McCarthy. Nordic Lake had direct input of high nitrate/ammonia via Buckles Creek and no anthropogenic phosphorus sources.

Esten Lake was influenced by nitrate/ammonia inputs to its eastern end through the Buckles Creek-Nordic Lake drainage. In addition, primary sewage effluent from the Angel Lake plant (STP #2) was a source of additional nutrients including phosphorus. The pending diversion of the Buckles Creek-Nordic Lake inflows from Esten Lake and the input of tertiary treated sewage effluent to the diverted flow provided importance to the establishment of a data baseline prior to the unloading of Esten Lake from its nutrient inputs.

Depot Lake was not influenced by direct inputs of either nitrogen or phosphorus, but was to receive the diverted nitrogen-rich flow from Nordic lake and the consolidated effluent flow from the new sewage treatment plant. Baseline water quality information was required.

FIGURE 6

WESTERN ARM OF THE SERPENT RIVER SYSTEM



McCarthy Lake was the point where the nutrient influenced flow of the western arm of the Serpent River System joined with the nitrate/ammonia rich flow of the combined eastern and central arms of the Serpent River. In addition to evaluating the influence of the nitrogen source, the pending short-circuiting of nutrient rich flows to Depot Lake made baseline data collection desirable for McCarthy Lake.

B Lakes included Elliot and Unnamed Lake, a small waterbody between Nordic Lake and Esten.

Elliot Lake is the source for the municipal water supply and doubles as an important recreational waterbody for the town. It receives a limited anthropogenic nutrient input from urban runoff and the outflow from Horne Lake and its secondary sewage treatment plant. Elliot Lake was designated an upstream control study lake.

Unnamed Lake is situated downstream of Nordic Lake and receives the nitrogen rich flow from the Buckles Creek system. Since it has no anthropogenic sources of phosphorus, water quality data were useful in examining the influence of nitrates/ammonia alone on lake trophic status.

The C lakes, Marshland, Grandeur and Trout are located downstream of the Esten Lake outflow and flow into Depot Lake. They are of secondary interest in the establishment and maintenance of background water quality records prior to the nutrient unloading of Esten Lake proper.

Morphometric data for the study lakes are summarized in Table 1.

TABLE I: LAKE MORPHOMETRY

	SURFACE AREA (hectares)	MEAN DEPTH (metres)	VOLUME (metres ³ x 10 ⁶)
NORDIC	114.93	6.6	7.54
ESTEN	416.84	14.1	58.77
DEPOT	206.0	7.8	16.07
MCCARTHY	657.9	6.1	40.13
ELLIOT	615.95	15.6	92.09
UNNAMED	13.96	7.5	1.05
MARSHLAND	107.65	5.5	5.92
GRANDEUR	106.84	8.0	8.55
TROUT	40.47	5.6	2.27

FIELD METHODS

The field techniques used varied with both the season and lake from which the samples were collected. In the spring all of the study lakes were examined in the same manner. Water samples were collected at each primary basin station (Figure i through vi, Appendix I) and analyzed for standard chemical parameters, metals and nutrients, (Table 2). On the larger study lakes additional nutrient samples were taken at secondary stations in order to allow determination of spring phosphorus averages (Dillon 1974).

For the summer sampling the study lakes were classified into three categories, A, B, and C, according to the intensity with which they were studied. The A lakes were sampled according to the schedule outlined in Table 3 beginning in May, 1981. The B lakes, Elliot and Unnamed Lake were sampled according to the schedule outlined in Table 3, beginning in June 1981.

The C lakes, or least sampled lakes, were sampled once, on September 23, 1981.

Water samples, except the bottom samples, were collected using a weighted composite can sampler and 1 litre glass bottle. During the spring, and summer, the composites were collected through the photic zone (twice the Secchi disc depth). The bottom samples were collected at approximately 2m above the sediments using 1.5 l P.V.C. Kemmerer sampler.

Lake samples collected for phosphorus determination were filtered through an 80u mesh net to remove detrital lumps and suspended matter. Benthos and sediment samples were

Table 2

Laboratory Methods:

The following analyses were performed on field samples.

Water Chemistry	Dissolved Organic Carbon	
	Dissolved Inorganic Carbon	
	pH	
	Conductivity	
	Total Alkalinity	
	Total Hardness	
	Apparent Color	
	Calcium	
	Magnesium	
	Sodium	
	Potassium	
	Iron	
	Chloride	
	Reactive Sulphate	
Metals	Copper	
	Nickel	
	Lead	
	Zinc	
	Cadmium	
	Chromium	
	Aluminum	
Nutrients	Nitrogen	Total Filtered Ammonium
		Filtered Nitrite
		Filtered Nitrite and Nitrate
		Total Kjeldahl Nitrogen
	Phosphorus	Total Phosphorus
Sediments	Total Phosphorus	
	Total Nitrogen	
	Loss on Ignition	
	Metals - Zinc, Iron, Cadmium,	
	Chromium, Lead,	

Nickel, Aluminum,
Copper.

Analyses were completed at the Toronto Laboratory of MOE in accordance with standard methods (1981).

TABLE 3 SAMPLING SCHEDULE

Study Parameters	Lake Type		
	A	B	C
Secchi Disc	2	1	●
Chlorophyll	2	1	●
Phytoplankton	2	1	
Phosphorous	2	1	●
Nitrogen	2	1	●
Zooplankton	2	1	
Water Chemistry	1	1	●
Bottom Water Chemistry	1	1	●
Bottom Phosphorous	1	1	●
Bottom Nitrogen	1	1	●
D.O.T. Profile	1	1	●
Metals	▲	▲	●
Benthos	■ ▲	■ ▲	
Sediments	■ ▲	■ ▲	

D.O.T. = Dissolved Oxygen-Temperature

2 = Measured Twice Per Month

1 = Measured Once Per Month

● = Measured Once On Sept./23/81

▲ = Measured Once In The Fall

■ = Measured Once In Early Summer

collected with a 15x15 cm Ekman dredge. Benthos samples consisted of 5 dredges pooled to a single sample per station, while the sediment samples consisted of 3 dredges pooled to a single sample per station.

Zooplankton samples were collected using a 30 cm diameter 80 μ mesh plankton net, hauled vertically from approximately 2 m above lake bottom.

The dissolved oxygen temperature profiles were determined using a Y.S.I. model 57 or model 54 oxygen meter.

In order to monitor the ammonia/nitrate access from North Nordic lake through Nordic to Esten Lake, it was necessary to establish several sampling sites on Buckles Creek. At stations 1 through 6, nutrients, pH and temperature were measured on a bi-monthly basis. Water chemistry samples were collected monthly.

Phytoplankton composition and biomass were determined as monthly composites of bi-weekly samples for the A lakes and as seasonal composites for the B lakes.

Zooplankton composition and biomass were determined as seasonal composites of bi-weekly samples for the A lakes and seasonal composites of monthly samples for the B lakes. Samples were identified and counts of dominant zooplankters were converted to biomass estimates as described by Yan and Strus (1980).

DATA ANALYSIS

The relationship of inorganic nitrogen concentrations in study lake basins with the common trophic status indicators: Secchi disc visibility, chlorophyll a, phytoplankton and zooplankton biomass, and total phosphorus, was investigated through the development of a correlation matrix (Snedecor and Cochran 1978). In addition, analytical results were categorized into three data sets consisting of biotic factors, (chlorophyll a, phytoplankton and zooplankton biomass) chemical factors (inorganic nitrogen, total phosphorus, alkalinity, pH, conductivity, sulphate, inorganic carbon) and mean annual zooplankton abundance. Multivariate statistical analyses including clustering and principal components analysis were carried out using the CLUSTAN package (Wishart 1975).

Zooplankton abundance data were transformed by $(\log_{10}(x+1))$ prior to clustering. Principal components analysis on a lake basin by chemical parameter matrix was performed on $\ln(x)$ transformed data.

RESULTS

Results of water chemistry and sediment analyses for all lake and stream sampling locations are published in MOE (1982).

Dissolved oxygen and temperature profiles for study lakes are shown in Appendix 2.

The results of the evaluation of biological parameters including phytoplankton, zooplankton and benthos community composition are included in Appendix 3.

Chlorophyll a and Secchi disc visibility for the study lakes are summarized in Appendix 4.

Summary diagrams for select analytical variables are presented in the following series of figures:

Figure 7 shows the mean total inorganic nitrogen concentrations (NH_3 plus NO_3) for the Buckles Creek sampling stations. High concentrations of nitrogen originate at the outlet of North Nordic lake and are carried through the creek in diminishing concentrations to Esten Lake.

The mean total inorganic nitrogen concentrations for the type A and B lakes of the Serpent River's western arm are shown in Figure 8. Highest concentrations were encountered in the Buckles Creek drainage and in McCarthy Lake which is influenced by the inflow of the main channel of the Serpent River.

Figure 9 summarizes the mean total phosphorus distribution through the study lakes. Relatively high concentrations were

FIGURE 7
BUCKLES CREEK SYSTEM
-MEAN TOTAL INORGANIC NITROGEN (mg/L) -

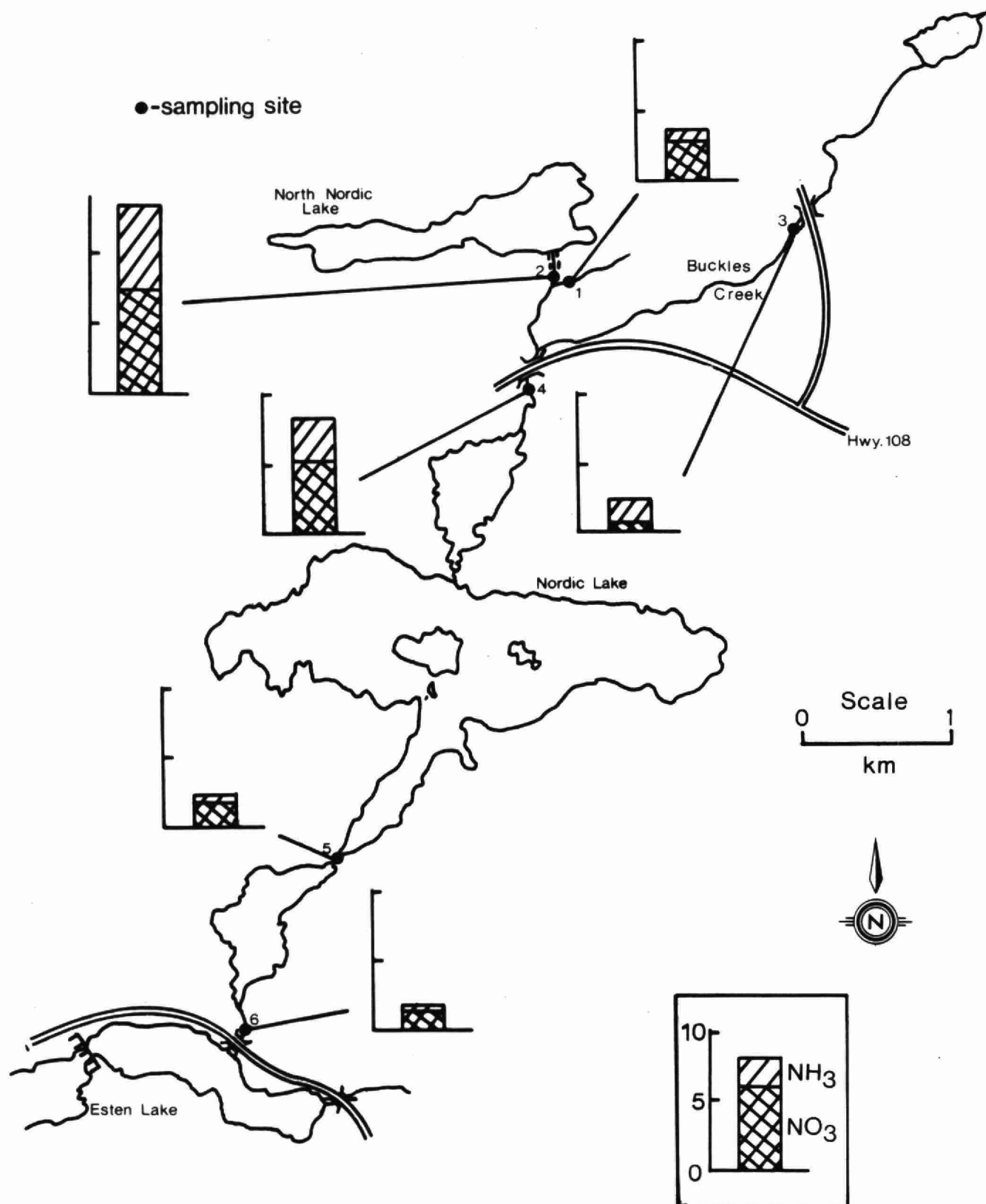


FIGURE 8

MEAN TOTAL INORGANIC NITROGEN CONCENTRATIONS (mg/L)

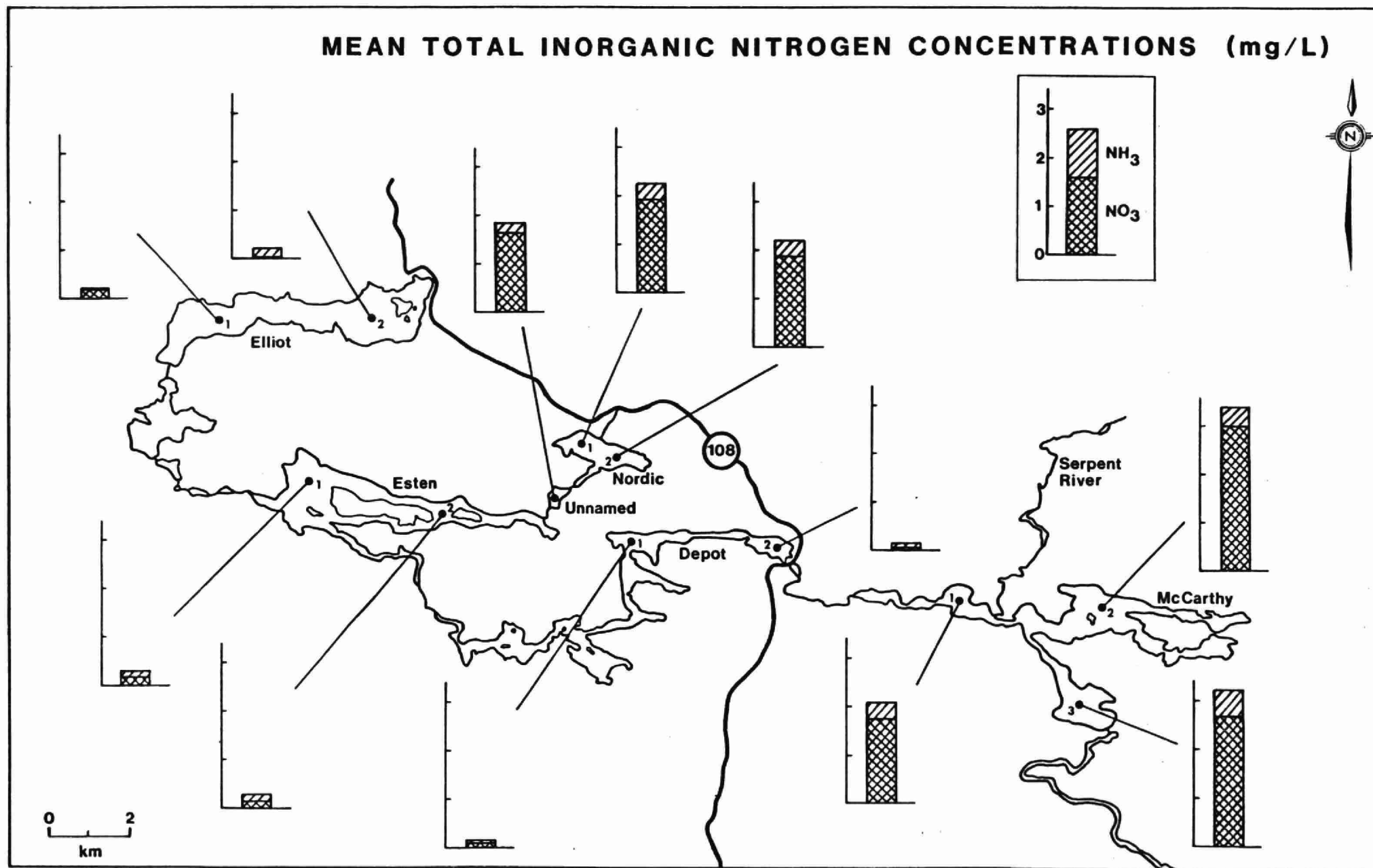
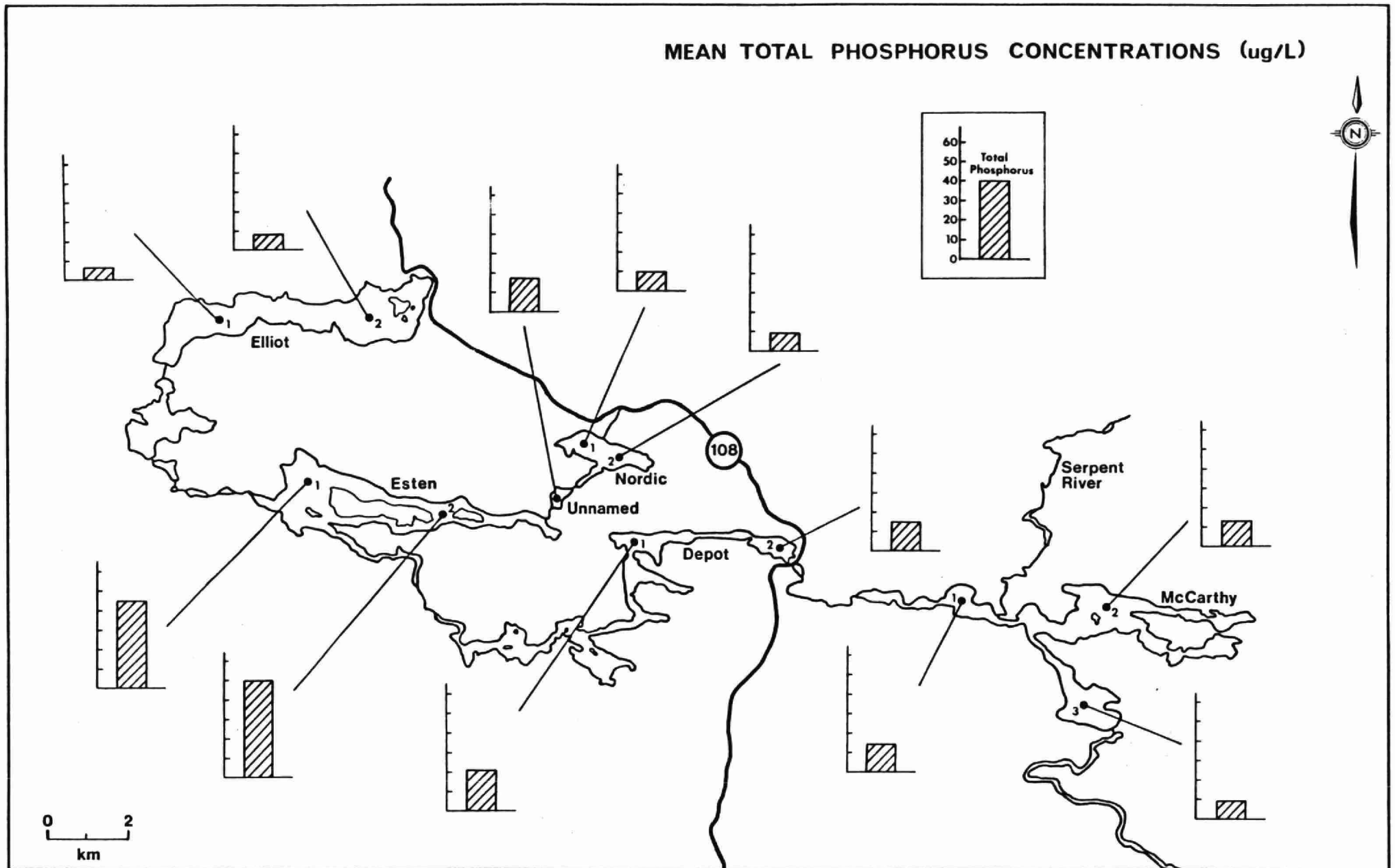


FIGURE 9

MEAN TOTAL PHOSPHORUS CONCENTRATIONS ($\mu\text{g/L}$)



observed in Esten Lake. Moderate values were found in Unnamed, Depot and at Station 1 of McCarthy Lake while relatively low means characterized the remaining sampling locations.

Mean chlorophyll a concentrations are shown in Figure 10. Highest values were found in Esten Lake while the lowest concentrations of chlorophyll a were discovered in Nordic, Unnamed and two of the McCarthy Lake locations.

Mean phytoplankton biomass, Figure 11, exhibited a distribution pattern similar to that of chlorophyll a. Concentrations were highest in Esten Lake and lowest in Nordic, Unnamed and stations 2 and 3 of McCarthy Lake.

Zooplankton biomass, Figure 12, did not follow the distribution pattern established by other important study parameters within the lake system.

The results of the cluster analysis for zooplankton abundance data are summarized in Figure 13. Three distinct groupings of abundance versus lake basin were identified.

Figure 14 presents the results of cluster analysis for biotic parameters including mean summer chlorophyll a, zooplankton biomass and ice free period phytoplankton biomass. Segregation into four distinct groupings was apparent.

The results of principal components analysis for the chemical data are shown in Figure 15. Again, three groupings of lake basins could be defined.

The correlation matrix for mean concentrations of trophic status indicator parameters in each lake basin is shown in Table 4.

FIGURE 10

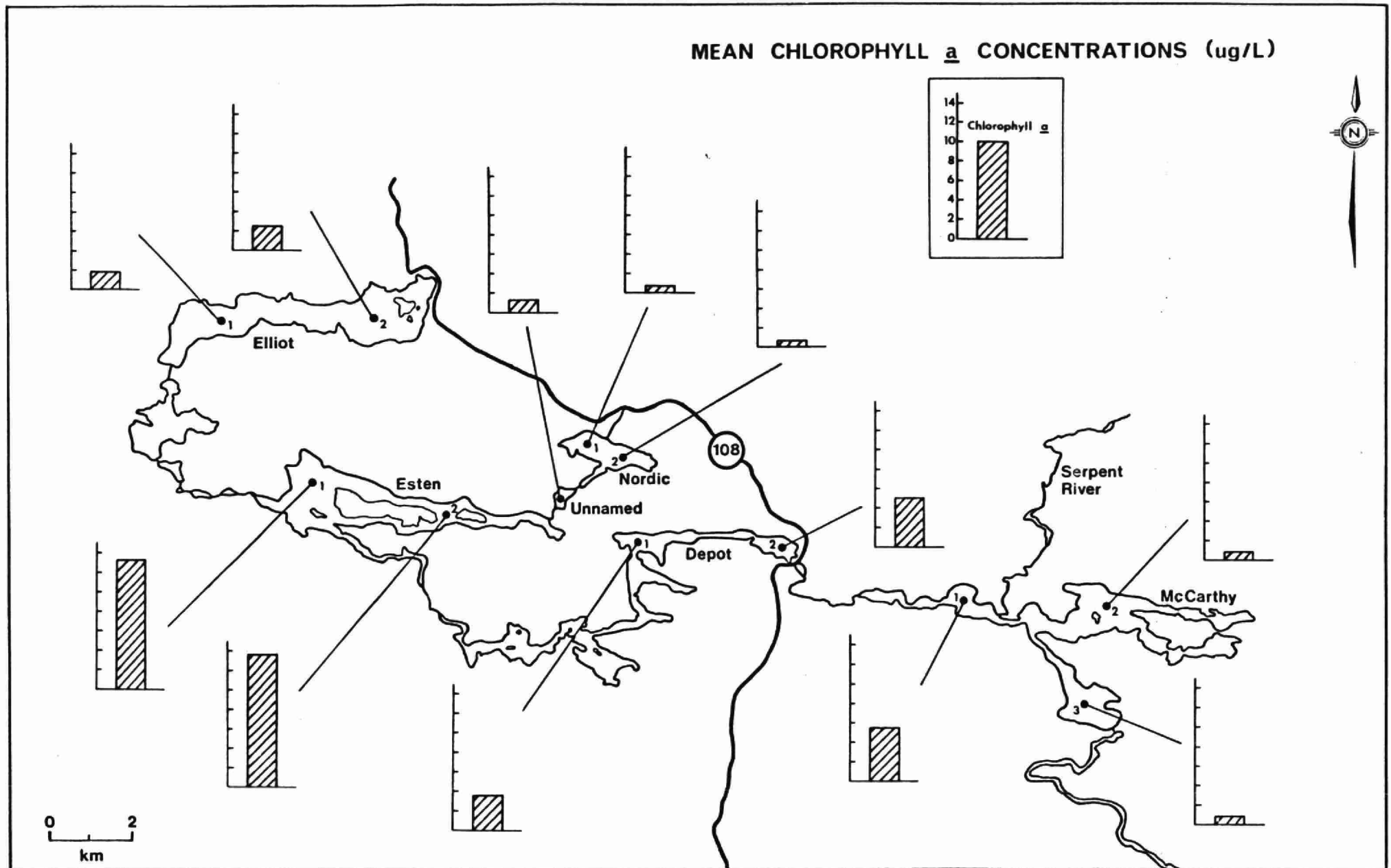


FIGURE 11

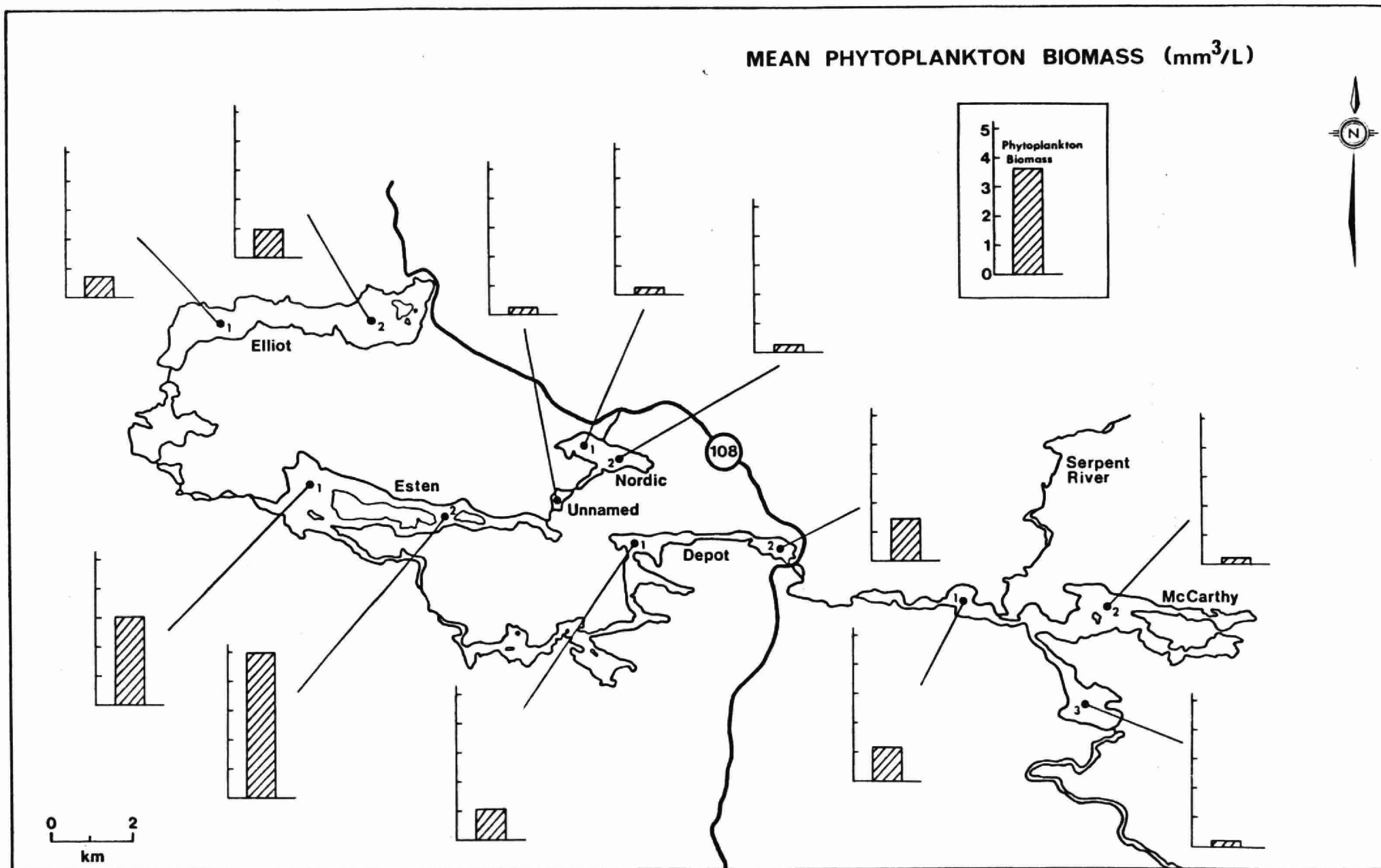


FIGURE 12

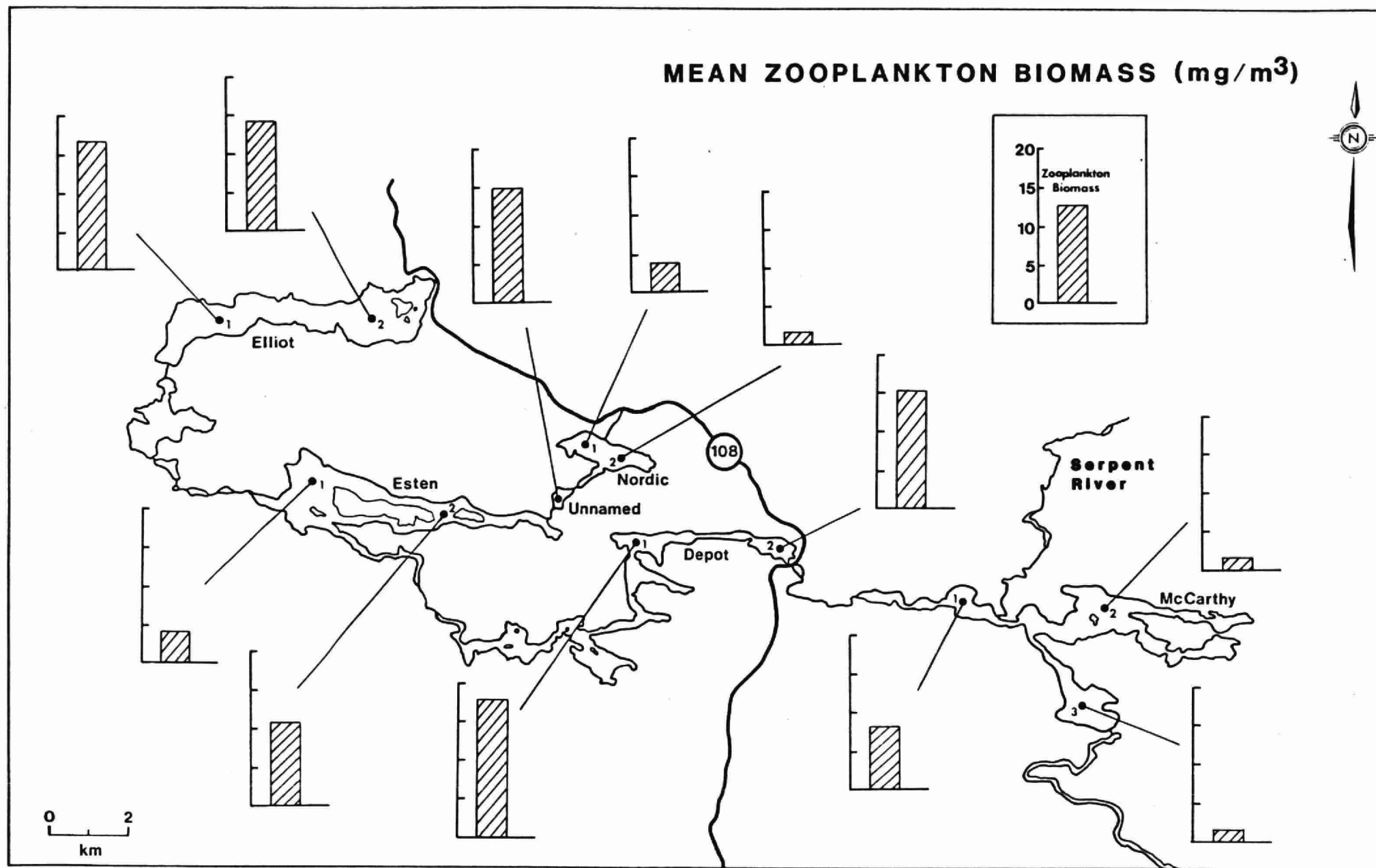


FIGURE 13

**DENDROGRAM OF CLUSTER ANALYSIS
ZOOPLANKTON ABUNDANCE, 1981**

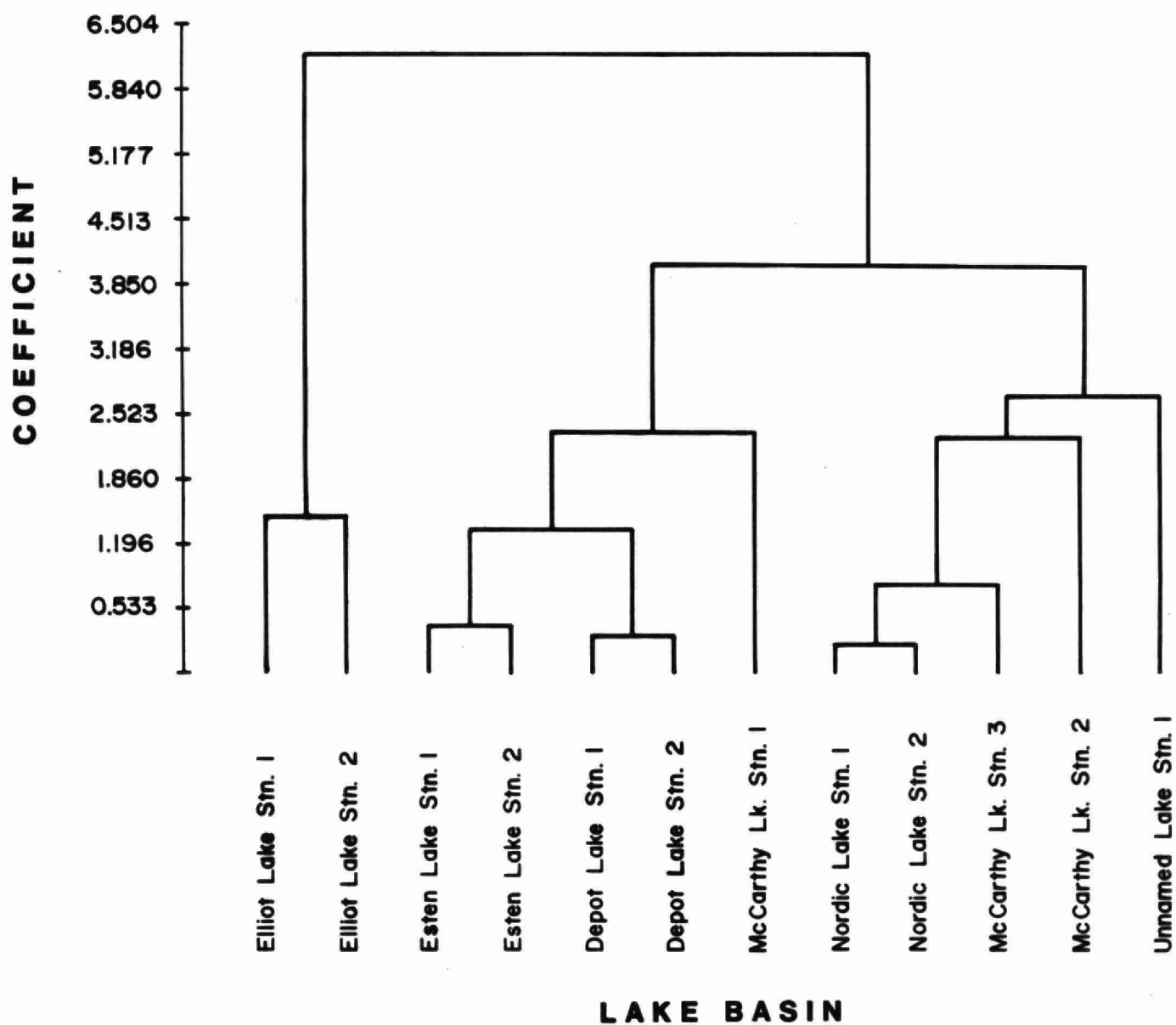


FIGURE 14

**DENDROGRAM OF CLUSTER ANALYSIS
BIOTIC PARAMETERS, 1981**

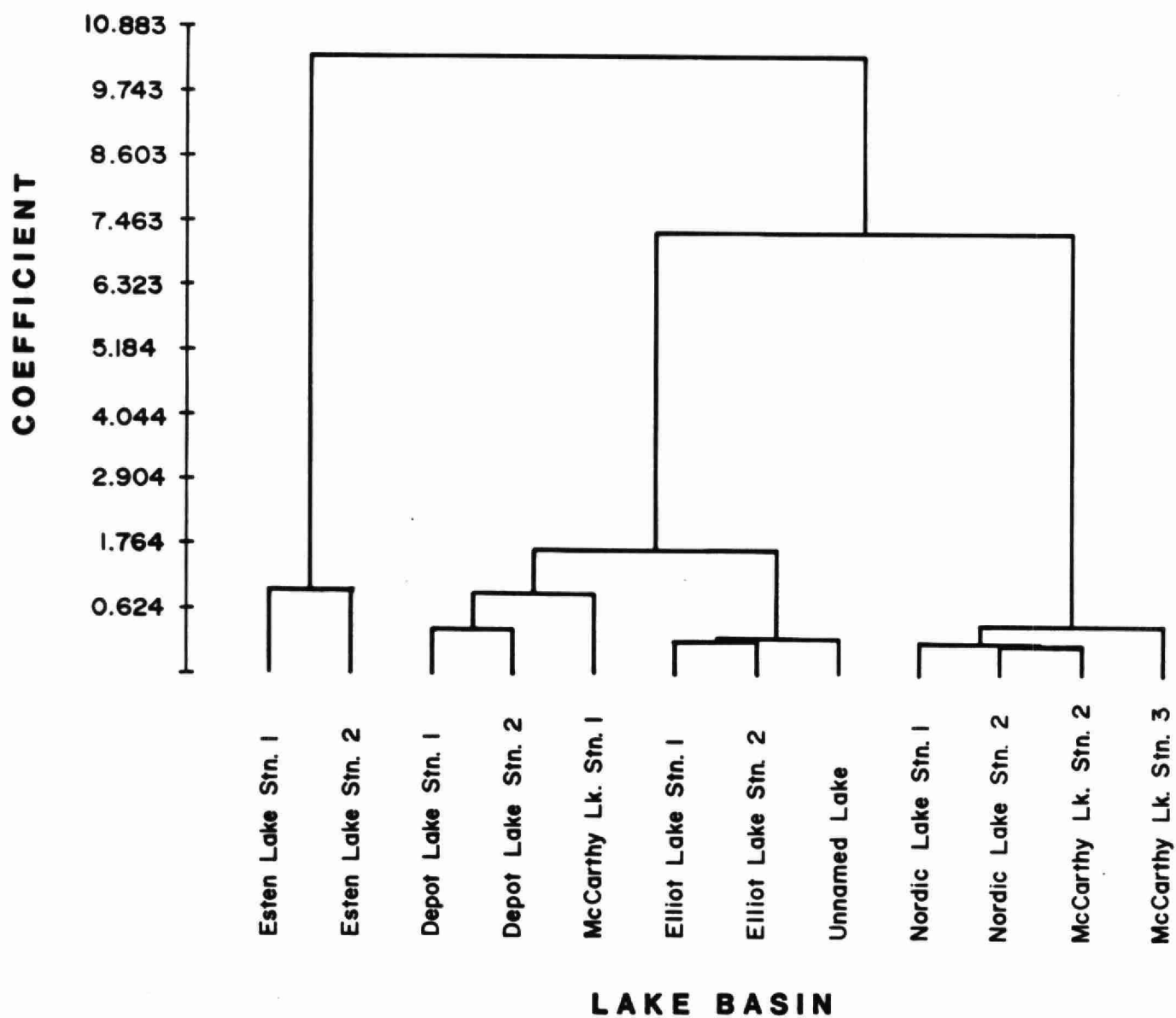
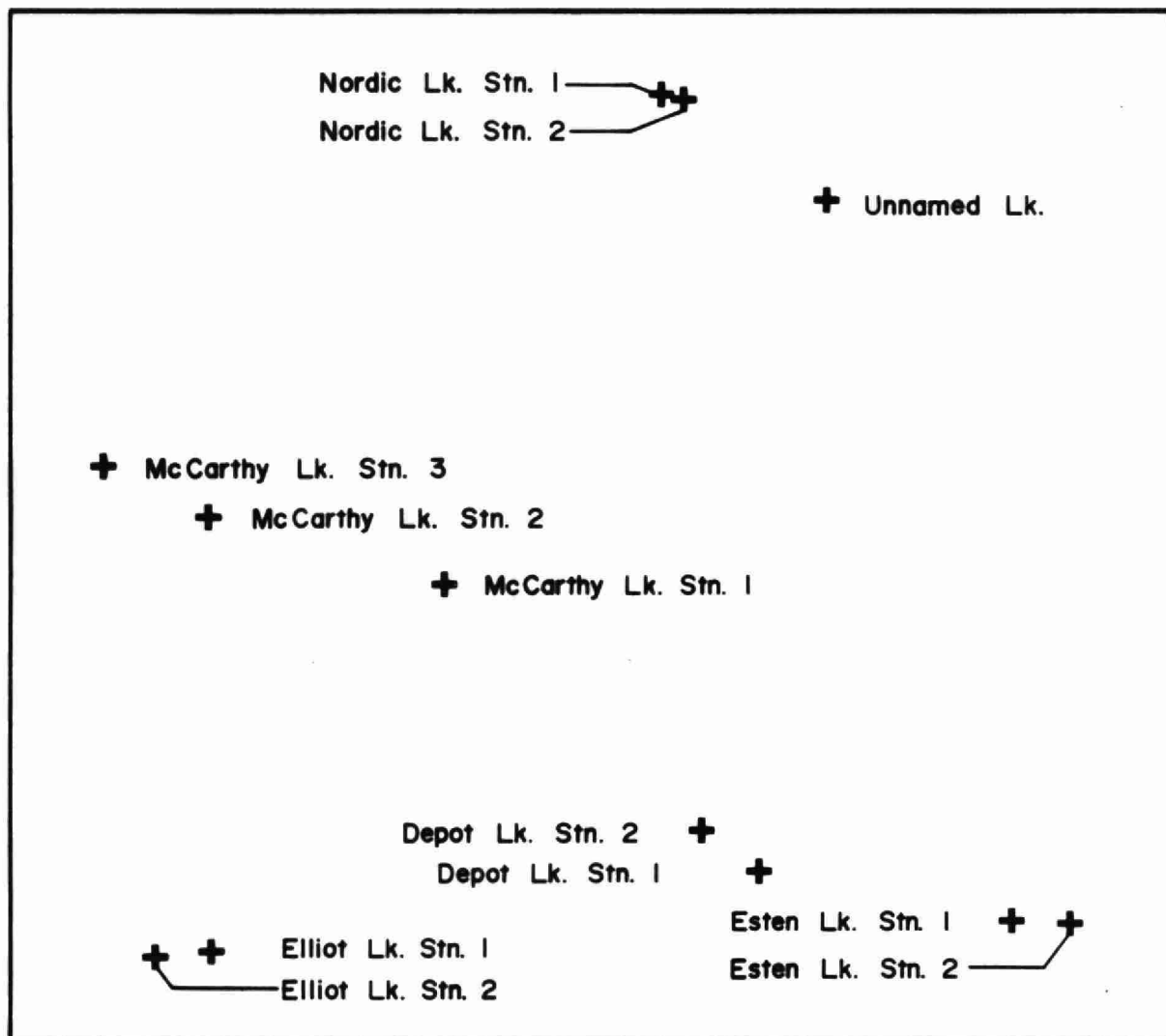


FIGURE 15

PRINCIPAL COMPONENTS ANALYSIS CHEMICAL PARAMETERS

FACTOR 1



DISCUSSION

a) Water Chemistry

The western arm of the Serpent River is a two part system receiving relatively unaffected water from Elliot Lake and mining impacted flows from the Buckles Creek - Nordic Lake system. The clean flow from the Elliot Lake drainage basin combines in Esten Lake with the nitrogen and dissolved solids laden flow from Nordic Lake, and is diluted through the Marshland-Grandeur-Trout-Depot Lake chain. Mixing with the main branch of the Serpent River occurs in McCarthy lake where additional nitrogen and dissolved solids accrue.

A LAKES

Nordic Lake

The water chemistry of Nordic Lake has been and continues to be influenced primarily by the high dissolved solids content of the nitrogen rich Buckles Creek inflow. The epilimnetic waters of Nordic Lake were characterized by a high load of dissolved solids composed mainly of sulphates (280 mg/L). The pH was near neutral (6.7-7.1 units) and the presence of high quantities of calcium and magnesium resulted in a hard-water classification. Nutrient concentrations were mixed in that inorganic nitrogen was abundant (2.3 mg/L) while phosphorus was relatively scarce (9.6 ug/L). The nitrogen to phosphorus ratio was calculated as 240:1. Inorganic carbon concentrations were also low averaging 1.9 mg/L.

Hypolimnetic conditions in the two basins of Nordic Lake were radically different. In the shallow western basin the

hypolimnetic waters reflected the chemical composition of the surface waters while the deeper basin was characterized by a dissolved solid-based meromixis below a depth of 18m. Concentrations of dissolved substances in the meromictic zone were approximately triple those of the surface waters. Nitrogen was present primarily in the ammonia form suggesting anaerobic reducing conditions.

Esten Lake

The water chemistry of Esten Lake was controlled by the mixing of the flow from Elliot Lake and that from the Buckles Creek-Nordic Lake system. Concentrations of dissolved solids as reflected by the conductivity readings (180 umho/cm) were moderate but much lower than those of Nordic Lake. The epilimnetic waters were classified as moderately soft (hardness 54 mg/L) and pH readings were generally basic. Sulphate concentrations (45 mg/L) were still elevated in comparison to expected background values for Shield lakes (Rep. MOE 1978).

Inorganic nitrogen concentrations in the surface water averaged 0.287 mg/L lakewide while total phosphorus averaged a high 47 ug/L. The nitrogen to phosphorus ratio was a low 6:1 value. Average concentrations of nitrogen and phosphorus were slightly higher in the eastern basin of Esten Lake due to its proximity to the Nordic Lake inflow.

Inorganic carbon concentrations (2.6 mg/L) were moderately low.

Concentrations of chemical parameters in the hypolimnetic waters of the two Esten Lake basins were higher than those of

their epilimnetic zones. In addition, concentrations of dissolved substances at the sampling station nearest the Nordic Lake inflow generally exceeded the hypolimnetic concentrations detected at the west end of Esten Lake.

The dominant form of nitrogen was nitrate, reflecting the oxidizing environment present.

Depot Lake

Depot Lake is separated into two distinct basins by a shallow-constriction near its midpoint. The lake's water chemistry is the product of the Esten Lake outflow and runoff from the drainage area downstream of Esten Lake.

There is little difference chemically between epilimnetic zones of both basins. Dissolved solids concentrations as reflected by conductivity measurements (161 $\mu\text{mho/cm}$) are moderate, but lower than those of Esten Lake. Near neutral pH values are common while hardness (49 mg/L) remains in the moderately soft range. Sulphate concentrations are still moderately high (44 mg/L).

Of the nutrient parameters, inorganic nitrogen concentrations in the epilimnetic waters of Depot Lake were uniformly distributed averaging 0.158 mg/L while phosphorus concentrations were moderate. Total phosphorus concentrations averaged 20.7 $\mu\text{g/L}$ at station 1 and 15 $\mu\text{g/L}$ at station 2. The N:P ratios were 7.8:1 and 10.3:1 respectively. Inorganic carbon concentrations were moderately low averaging 2.7 mg/L.

The hypolimnetic waters of the deeper western basin (Station 1) exhibited a clear seasonal trend generally associated with the development of reducing conditions. Ammonia and iron concentrations increased while concentrations of nitrates declined. The shallower outlet basin also exhibited a similar tendency; but a sampling anomaly appeared in August when the hypolimnetic sample reflected surface water conditions.

McCarthy Lake

The water chemistry of McCarthy Lake is partially influenced by the outflow of Depot Lake; however, the major input of chemical parameters is through the incoming Eastern Arm of the Serpent River.

Although the flow of the Eastern Arm of the Serpent River through McCarthy Lake was visually apparent from its blue-green coloration, clarity and discernable flow patterns, the magnitude of its influence on the water chemistry of the three widely separated basins of the lake was unexpected.

Station 1 at the west end of McCarthy Lake was expected to reflect the outflow water chemistry of Depot Lake; yet, concentrations of dissolved solids were higher than for Depot Lake and increased throughout the sampling period. Sulphate concentrations averaged 59 mg/L. Hardness values, averaging 63 mg/L, were higher in the moderately soft range due to the increased concentrations of calcium while pH values remained near neutral (6.5-7.4 units).

Total inorganic nitrogen averaged 2.1 mg/L while phosphorus concentrations were moderate at 13.6 ug/L. The nitrogen to phosphorus ratio was 154:1.

Inorganic carbon concentrations were moderately low and declined to low values through the summer.

Hypolimnetic water chemistry in the shallow Station 1 basin was characterized by a slightly lower dissolved solids content than that of the epilimnion. Nitrate concentrations declined while iron increased in the late summer in association with the reduction of hypolimnetic dissolved oxygen. Lake turnover was complete by mid-October.

The remaining basins of McCarthy Lake exhibited water chemistry characteristics influenced by the flowthrough of the Eastern Arm of the Serpent River. The eastern basin, Station 2, showed the minor dilutionary influence of its local watershed in that concentrations of dissolved chemical parameters were slightly lower than in the main channel of the river as represented by Station 3. Nutrient analyses for epilimnetic waters of Station 2 revealed a high average inorganic nitrogen concentration of 2.9 mg/L while phosphorus averaged a moderate 13.5 ug/L. The N:P ratio was a high 216:1 by weight. Inorganic carbon concentrations were low (1 mg/L).

Hypolimnetic concentrations of dissolved substances were lower than in the epilimnion as a result of thermal stratification developing over the relatively more dilute post ice breakup waters.

At Station 3 on McCarthy Lake epilimnetic inorganic nitrogen concentrations averaged a high 3.2 mg/L while phosphorus concentrations were low averaging 9.5 ug/L.

The N:P ratio was 337:1. Inorganic carbon concentrations were also low at 0.87 mg/L.

Hypolimnetic waters reflected concentrations of chemical parameters in the epilimnion but were slightly more dilute. Nitrate remained the dominant form of nitrogen indicating the presence of oxidizing conditions in the hypolimnion.

B LAKES

Elliot Lake

The monthly sampling frequency for two basins on Elliot Lake, the designated control lake, showed it to be a near neutral, moderately soft (hardness 23 mg/L) relatively dilute waterbody (conductivity 110 umho/cm). Sulphate concentrations were moderately low at 25.5 mg/L.

Epilimnetic inorganic nitrogen concentrations averaged 0.225 mg/L while phosphorus values were a low 7.8 ug/L. The N:P ratio was 29:1. Inorganic carbon concentrations were low averaging 1 mg/L.

The monitoring of hypolimnetic water chemistry did not reveal the presence of unusual conditions.

Unnamed Lake

The chemical composition of this small waterbody was influenced by the outflow of Nordic Lake. There was little difference chemically between epi and hypolimnetic waters.

Unnamed Lake contained high concentrations of dissolved solids (conductivity 600 umho/cm) with sulphate (250 mg/L) a major component.

Inorganic nitrogen was moderately high averaging 1.8 mg/L while phosphorus averaged 17.5 ug/L. However, it is expected that the phosphorus average was pushed upwards by two unexpectedly elevated determinations. The nitrogen to phosphorus ratio was 103:1 and inorganic carbon values were moderately low at 2.3 mg/L.

C LAKES

Marshland, Grandeur, Trout

The water chemistry of these lakes was governed by the out-flowing water quality of Esten Lake and runoff from their individual watersheds.

During the spring sampling these lakes were characterized by near- neutral pH values and declining loads of dissolved substances with distance from Esten Lake. Concentrations of dissolved materials were between the values detected for Esten and Depot Lakes.

Spring turnover concentrations of phosphorus in the lake system ranged between 24 and 39 ug/L while inorganic nitrogen values declined from 0.74 mg/L in Marshland Lake to 0.25 mg/L in Trout Lake.

During the autumn sampling, concentrations of dissolved solids in the epilimnetic waters were slightly higher than during the spring runoff period.

Hypolimnetic inorganic nitrogen concentrations were predominantly in the ammonia form reflecting reducing conditions at the basin stations.

b) Metals

Concentrations of copper, nickel, lead, zinc, cadmium, aluminum and chromium were monitored during the spring and autumn in the epilimnetic waters of each lake. The significance of concentrations encountered was interpreted on the basis of the Provincial Water Quality Objectives (MOE 1978).

Overall, concentrations of metals were very low. Nickel, chromium, copper, zinc and aluminum were consistently below the objectives while lead and cadmium were occasionally at or slightly higher than the objectives. There was no evidence of consistently elevated metal concentrations.

c) Chlorophyll a - Secchi Disc

The analytical determination of chlorophyll a measures the amount of photosynthetic green pigment in algae. Although the chlorophyll a content per unit of cell mass can be various (Nicholls and Dillon 1978), the chlorophyll a concentration has been found to be a useful indication of primary biological activity and a suitable substitute for determination of algal biomass (Michalski et al 1973, Nicholls 1976).

The classification of trophic status on the basis of chlorophyll a concentration has been practiced for a number of years. Slight variations in concentration limits denoting trophic status categories are apparent. The classification

system adopted for Ontario's northeastern region lakes uses the ranges of ice-free chlorophyll a concentrations listed below (Dillon 1974).

Chlorophyll a concentrations less than 2 ug/L are low and suggestive of oligotrophic conditions. Concentrations between 2 and 4 are moderate suggesting mesotrophic conditions while a mean chlorophyll a range between 5 and 10 ug/L is considered high indicating a mesoeutrophic status. Chlorophyll a concentrations in excess of 10 ug/L are associated with eutrophic lakes.

Water clarity in lakes is governed by a variety of factors (Brezonik 1978). The amount and size distribution of particulate matter including planktonic algae, zooplankton, bacteria and other suspended matter of both organic and inorganic origin are thought to be the prime factors. In addition, the color of dissolved organic material and the natural light absorption properties of water can influence a lake's water clarity.

The use of water clarity determinations through Secchi disc visibility reading is based on the approximation that the quantity of pigment-containing phytoplankton, is the principal factor determining clarity. The correlation of Secchi disc visibility and chlorophyll a concentrations in numerous lakes has supported this approximation (Edmondson 1972, Bachman and Jones 1974, Dillon and Rigler 1975, Carlson 1977). A trophic state index based on Secchi disc visibility has been proposed by Carlson 1977, 1980.

Although the simple use of the chlorophyll a-Secchi disc relationship to establish trophic status of lakes is fraught

with drawbacks (Lorenzen 1980 Megard 1980) the Secchi disc does have a useful place in limnology. Long term changes in water clarity are generated by changes in the abundance of phytoplankton brought about by eutrophication (Edmondson 1980). Over a short period of monitoring in a system of associated lakes the determination of mean ice-free chlorophyll a concentrations and the water clarity can produce an indication of trophic conditions. In addition the chlorophyll-Secchi disc relationship can provide a relative trophic classification for lakes being studied at the same time.

Chlorophyll a Distribution

Mean chlorophyll a concentrations for the study lakes mimicked the distribution of phytoplankton biomass. High concentrations (greater than 13 ug/L) occurred in Esten Lake. Moderately high (greater than 5 ug/L) concentrations were found at the outlet basin of Depot Lake and the inlet of McCarthy Lake, and moderate concentrations at station 1 of Depot Lake and Elliot Lake. At all other sampling locations, low concentrations of less than 2 ug/L chlorophyll a were recorded.

Secchi Disc Visibility

The plotting of mean Secchi disc visibilities for the basin stations of the type A and B study lakes showed very good light transparency in excess of 6 metres for Stations 2 and 3 on McCarthy Lake and both Nordic Lake sampling locations. Mean visibilities between 5 and 6m were determined for Elliot Lake, with Station 2 less clear than Station 1, Unnamed Lake and Station 1 of both McCarthy and Depot Lakes.

Station 2 of Depot Lake had a mean Secchi disc visibility of slightly less than 5m while both Esten Lake stations were characterized by substantially lower light transparencies of approximately 3.5m. Although some of the Secchi disc-Chlorophyll a means did not fall within the general range of limits established for lakes in northeastern Ontario (MOE unpublished), an inverse relationship between the two variables was apparent.

d) Phytoplankton Biomass and Composition

Trophic status of lakes is usually determined by the measurement of specific water quality parameters which are associated with the degree of biological productivity. Of these trophic status indicators, chlorophyll a has been treated as a surrogate measurement for phytoplankton biomass. The general neglect of phytoplankton biomass has been related to its difficulty of determination (MOE 1983). When biomass determinations are available they can be used as supporting information in the study of trophic status (Nicholls 1976). Correlations between total phosphorus, a strong trophic status indicator, and phytoplankton biomass have been found (Kalff and Knoechel 1978, Schindler et al 1978). Lakes with phytoplankton densities less than $1\text{mm}^3/\text{L}$ are usually associated with clear oligotrophic lakes while those with densities greater than $20\text{mm}^3/\text{L}$ denote hypereutrophic conditions.

Average phytoplankton densities for the study lakes are summarized in Figure 11. The highest mean phytoplankton densities occurred in Esten Lake where biomass at Station 2 approached $5\text{mm}^3/\text{L}$ while at Station 1, a biomass value of

approximately $3\text{mm}^3/\text{L}$ was recorded. Moderate biomass densities (greater than $1\text{mm}^3/\text{L}$) were developed at Stations 1 and 2 of Depot Lake and at Station 1 in the western basin of McCarthy Lake. Phytoplankton biomass determinations for Elliot Lake were moderately low and below $1\text{mm}^3/\text{L}$. Low biomass (less than $0.3\text{mm}^3/\text{L}$) characterized Nordic and Unnamed Lakes, and the remaining McCarthy Lake basins.

Nordic Lake

The two basins of Nordic Lake exhibited similar patterns of phytoplankton composition and succession.

Overall, Bacillariophyceae dominated the phytoplankton community comprising 49% of the meagre biomass. Chrysophyceae were also an important group contributing 29% of the total ice-free biomass.

Seasonally, dominance of Chrysophyceae in April gave way to dominance of the Bacillariophyceae through August. A shift to Chrysophyte and Dinophyte importance was noted in the autumn samples. The two groups generally associated with conditions of nutrient enrichment, Cyanophyceae, and Chlorophyceae, were never prominent constituents of the phytoplankton. Maximum biomass values were recorded in May, June and July when Bacillariophyceae were dominant; however, biomass values less than $0.4\text{mm}^3/\text{L}$ are considered to be very low.

Esten Lake

The percentage composition of planktonic algae by class for both Esten Lake basins was similar when averaged over the

complete sampling period. Chlorophyceae were the dominant group comprising 54% of the algal biomass. Chrysophyceae were next in importance contributing 17% of the biomass followed by the Bacillariophyceae at 10%. The Cyanophyceae appeared to be a minor component at 6% of the total biomass.

The seasonal succession pattern for the phytoplankton of Esten Lake was also similar for both stations with slight variations. Chlorophyta were dominant from April to June followed by distinct pulses of Cryptophycean and Cyanophycean types in July and August. During September and October, no dominance by a single group of algae was apparent.

The phytoplankton biomass determinations were highest in the April to June sampling period with the single highest determination appearing in April at sampling location 2 when chlorophytes were dominant. At that time a biomass value of $15\text{mm}^3/\text{L}$ was recorded. The mean phytoplankton biomass determinations of $5\text{mm}^3/\text{L}$ at station 2 and $3\text{mm}^3/\text{L}$ at 1 were considered to be moderately high.

Depot Lake

As with Nordic and Esten Lakes there was little spatial difference in the relative percentage composition by class of phytoplankton when expressed on an ice-free period basis. The Chrysophycean group comprised 43% of the total biomass while the Bacillariophyceae were second in importance at 22%. Cryptophyceae contributed 15% of the biomass.

When examined on a seasonal basis, some differences in relative composition between sampling locations were observed. The generally applicable pattern of succession was

an early dominance by Chrysophycean and Bacillariophycean algae maturing to a Cryptophycean and Chlorophycean dominated community in June and July. A Cyanophycean pulse was evident at Station 2 in July. The Dinophycean group became important during August while Chrysophytes regained prominence during the autumn samplings.

Moderately high phytoplankton biomass determinations of 2.4 and $3.9\text{mm}^3/\text{L}$ were recorded at Station 1 and 2 for the May samples while the June to September values were moderately low at less than $1\text{mm}^3/\text{L}$. In October, moderate phytoplankton biomass of $1.5\text{mm}^3/\text{L}$ was determined.

McCarthy Lake

The summary percentage composition plots for the three sampling locations on McCarthy Lake reveal that similarities and differences existed among all three stations.

The Chrysophyceae dominated the phytoplankton biomass comprising 46, 50 and 56% of the total at Stations 1, 2 and 3 respectively. At Station 1, Dinophyceae were of secondary importance at 18% of the biomass while the Chlorophyceae made up 12%. At Stations 2 and 3 secondary dominance was reversed with Chlorophycean algae secondary in importance at 21 and 27%. Dinophyceae contributed 14% of the biomass at Station 2 while at Station 3 Bacillariophyceae were also important.

When the percentage composition of the phytoplankton community is examined on a monthly basis, a separation of Station 1 and a grouping of Stations 2 and 3 becomes apparent.

At Station 1, the Chrysophyceae-Bacillariophyceae dominated May community common to each lake station, gave way to a mid summer Chlorophyte-Dinophyte dominated assemblage. At Stations 2 and 3, the summer and autumn phytoplankton biomass was composed mainly of Chlorophytes and Chrysophytes.

Phytoplankton biomass at Station 1 was much higher than at Stations 2 and 3 where extremely low values were common through the complete sampling period.

A moderately high maximum biomass of $3.1\text{mm}^3/\text{L}$ was determined in May at station 1 while moderate biomass ($1\text{mm}^3/\text{L}$) persisted in the summer months.

Unnamed Lake

Phytoplankton composition and biomass was determined as an ice-free sampling period composite for the B lakes.

Bacillariophyceae were dominant comprising 57% of the algal biomass while Chrysophyceae were second in importance contributing 27% to the total. Cyanophycean and Chlorophycean flora were of very minor importance. The average phytoplankton biomass of $0.24\text{mm}^3/\text{L}$ was extremely low.

Elliot Lake

The two basins of Elliot Lake exhibited slight differences both in percentage composition by group and in phytoplankton biomass. Station 1, located away from the direct influence of the Town of Elliot Lake was dominated by a high percentage

of Bacillariophyceae (56%) with Chrysophyceae contributing 27% to the ice-free algal biomass.

At Station 2, Chrysophytes were the dominant biomass component at 42% of the total and Bacillariophytes were of secondary importance at 38%. Dinophyceae were more prominent components (7%) than at station 1 (0.3%).

Algal biomass for the Elliot Lake basins was moderately low at $0.7\text{mm}^3/\text{L}$ for Station 1 and $0.9\text{mm}^3/\text{L}$ for Station 2.

e) Zooplankton, Species Composition and Biomass

A total of 25 zooplankton species (16 cladocera and 9 copepoda) were observed in the six study lakes (Appendix 3). All species documented, except Eubosmina coregoni, Diaphanosoma birgei and Simocephalus serrulatus, are reported as common in non-acidic, oligotrophic lakes (Smith and Fernando 1978; Keller 1981, Jermalajev and Fraser 1982).

Species diversities, as measured by the number of species, were within the same range as those reported by Yan et al (1977), Yan and Strus (1980) and MOE (1983). However, relative to the control lake (Elliot) marked reductions in zooplankton diversity were apparent between lakes.

Both zooplankton standing crops (numbers of animals per litre) and calculated biomass estimates are significantly lower than those reported in the literature with average biomass values ranging from a low of 1.6 mg/m^3 in Nordic Lake to a high of 16.7 mg/m^3 in Elliot (Figure 12).

To objectively define differences in zooplankton communities between stations and lakes an agglomerative clustering strategy was employed on a species by station matrix (Wishart 1975). Calculated biomass values were used in this multi-variate analysis, with the estimated weights of the calanoid and cyclopoid copepodids proportioned to the respective species. Nauplii were excluded. Biomass values were employed because they better represented the relative ecological importance of each individual species to the overall zooplankton community.

The results of the cluster analysis shown in Figure 13 must be interpreted with a degree of subjectivity. The subjectivity arises when groupings or clusters are defined. In this case, groupings were defined by the "break of slope" technique (Sokal and Sneath 1963).

Zooplankton species abundance data defined three clustered groups. Cluster 1 included Elliot Lake by itself. Cluster 2 included all of Esten Lake, Depot Lake and Station 1 of McCarthy Lake. Cluster 3 was composed of the Nordic Lake stations, McCarthy stations 2 and 3, and Unnamed Lake.

Based on known waste discharges to these waterbodies and their resultant chemical characteristics, the three defined clusters can represent group separation composed of:

- (a) the control lake (Elliot),
- (b) those lakes and basins reflecting nutrient access responses (Esten, Depot, McCarthy 1),
- (c) lakes influenced primarily by industrial processes (Nordic, Unnamed, McCarthy 2 and 3).

f) Benthic Fauna

Several authors (Kitagawa 1978, Saether 1979 and Wiederholm 1980) have utilized profundal benthic faunal associations as indicators of lake trophic status and type. An attempt to apply these relationships was made by collecting five 15X15cm Ekman grabs at each sampling station in June and September. The results of these collections are present in Appendix 3.

Because of life history features the September sampling results were felt to be more representative for the study lakes (Resh, 1979).

Benthic invertebrate communities in the six study lakes were depauperate both in terms of species diversity(s) and standing crops. No macroinvertebrates were collected at either station in Esten Lake or from the meromictic station 2 in Nordic Lake. Unnamed Lake also had a limited benthic fauna.

For the remaining stations and lakes, the commonly employed benthic trophic status indicators such as indicator species/communities, oligochaete/chironomid ratio or oligochaete abundance did not hold true or could not be calculated because of the "pooled" form of the data.

g) Temperature and Dissolved Oxygen Distribution

The vertical distribution of dissolved oxygen during the period of thermal stratification can be an indication of lake

trophic status. A diagram showing the relationship between trophic status and vertical oxygen-temperature distributions is shown in Appendix 2 (Wetzel 1975).

During the summer stratification period, the oxygen distribution approximates the orthograde shape in oligotrophic or nutrient poor lakes. In eutrophic lakes, vertical dissolved oxygen concentrations are clinograde reflecting decreasing dissolved oxygen concentrations with depth.

Examination of dissolved oxygen and temperature profiles developed for the A and B study lakes during the 1981 period of sampling allows classification of oxygen regimes for individual lake basins into trophic status categories.

Areal hypolimnetic oxygen deficit (A.H.O.D.) is a measure of the rate of oxygen loss from the hypolimnion. The observation that there is a tendency in lakes of moderate depth for the relative areal deficit to increase with increasing productivity has allowed the use of A.H.O.D.'s as indicators of trophic status (Hutchinson 1938, 1957, Wetzel 1975). Arbitrarily, upper limits established for oligotrophy range between 0.5 and 0.75 mg O_2 cm⁻² month⁻¹ (167-250 mg O_2 m⁻² d⁻¹) while eutrophy is suggested by values in excess of the 1.0 to 1.65 range (333- 550 mg O_2 m⁻² d⁻¹). More recently, the unqualified use of A.H.O.D. in trophic status evaluation without the consideration of factors like hypolimnetic thickness and temperature, has been questioned (Charlton 1980).

Nordic Lake

The two basins of Nordic Lake displayed dissolved oxygen profiles that were influenced by basin depth (14m) at Station 1 and dissolved solids based meromixis below a depth of 20m at Station 2.

A positive heterograde oxygen distribution was developed at Station 1 with oxygen maxima at the thermocline. Some reduction in near-bottom hypolimnetic oxygen was observed in September. A.H.O.D. was very low at $56.3\text{mg O}_2\text{m}^{-2}\text{d}^{-1}$ likely complicated by photosynthetic oxygen production within the hypolimnetic zone.

When the meromictic layer (20-27m) of Station 2 is excluded from the evaluation of the oxygen distribution, a positive heterograde profile similar to that of the shallow basin is apparent. Hypolimnetic oxygen production may also have affected the low A.H.O.D. determination of $52\text{mg O}_2\text{m}^{-2}\text{d}^{-1}$.

Esten Lake

The basin depths for the Esten Lake study locations were in excess of 30m. Dissolved oxygen profiles for both basins revealed a similar pattern with the development and pronouncement of the clinograde distribution associated with the condition of nutrient enrichment. For both stations, thermocline based oxygen reductions were apparent.

A.H.O.D. values were calculated as 232 and $249\text{mg O}_2\text{m}^{-2}\text{d}^{-1}$ at Stations 1 and 2 reflecting the relative trophic status of Esten Lake. It was surprising that A.H.O.D. calculation suggested mesotrophic conditions when biological and chemical parameters indicated eutrophic conditions.

Depot Lake

The western basin of Depot Lake (Station 1) was moderately shallow with a maximum depth of 19m while the eastern basin (Station 2) was only 13m deep.

A positive heterograde oxygen distribution was maintained from June to August at Station 1 with a degeneration to a clinograde type by mid October. Relatively low hypolimnetic volume likely influenced the shape of the oxygen profile.

The areal hypolimnetic oxygen deficit was calculated as $257 \text{ mg O}_2 \text{ m}^{-2} \text{ d}^{-1}$.

Station 2 exhibited early development of the clinograde distribution associated with nutrient enrichment. As with the western basin, hypolimnetic volume was an influencing factor in the shape of the oxygen profile. An A.H.O.D. value of $191 \text{ mg O}_2 \text{ m}^{-2} \text{ d}^{-1}$ was likely affected by photosynthetic generation of oxygen in the hypolimnion.

McCarthy Lake

The basins of McCarthy Lake were classifiable into three distinct orders of depth. Station 1 was shallow with a maximum depth of 13m. The vertical dissolved oxygen distribution assumed the clinograde shape from the July determination till autumn lake turnover. A.H.O.D. was determined as $137 \text{ mg O}_2 \text{ m}^{-2} \text{ d}^{-1}$.

Station 2, the moderately deep eastern basin (28m), exhibited the favourable orthograde oxygen distribution indicative of a

low order of biological activity through the June to September sampling period. A tendency to the clinograde distribution was apparent in October. The A.H.O.D. of $184\text{mg O}_2\text{m}^{-2}\text{d}^{-1}$ was not indicative of the low order of biological activity suggested by the biotic data.

Station 3, the outlet basin, was moderately shallow with a maximum depth of 21m. As with Station 2, an orthograde dissolved oxygen profile persisted through September with an oxygen maximum at the thermocline. By October, a tendency to a clinograde oxygen distribution was evident.

The A.H.O.D. value of $43\text{mg O}_2\text{m}^{-2}\text{d}^{-1}$ reinforced the oligotrophic trophic status indication of the vertical oxygen profile.

Elliot Lake

Station 1 exhibited a healthy dissolved oxygen regime. The vertical distribution of oxygen maintained an orthograde to positive heterograde profile through the stratification period tending slightly to a clinograde distribution by mid October.

Areal hypolimnetic oxygen demand (A.H.O.D.) was calculated as $112\text{mg O}_2\text{m}^{-2}\text{d}^{-1}$.

Station 2, the eastern basin of Elliot Lake displayed a similar profile development from orthograde in June to positive heterograde through September. There was a stronger tendency to the clinograde distribution prior to autumn lake turnover than at Station 1.

A.H.O.D. was also higher than at Station 1 at $212\text{mg O}_2\text{m}^{-2}\text{d}^{-1}$ suggesting a tendency to mesotrophy.

Unnamed Lake

Dissolved oxygen profiles developed at the single, shallow basin of Unnamed Lake (12m) revealed a positive heterograde distribution with a dissolved oxygen maximum at the thermocline. This pattern persisted from June to August after which the development of a clinograde pattern emerged due largely to the meagre volume of hypolimnion present. An A.H.O.D. value of $94\text{mg O}_2\text{m}^{-2}\text{d}^{-1}$ suggested a low order of biological activity. However, hypolimnetic oxygen generation may have been a factor.

h) Data Analysis

The results of the cluster analysis for zooplankton abundance data (Figure 13) have been discussed previously.

Although zooplankton biomass values did not reflect the trophic condition of the study basins, the application of a lake basin/zooplankton abundance clustering strategy did result in the common grouping of nutrient influenced lakes and basins. Esten Lake, Depot Lake and McCarthy lakes's basin 1 were grouped together.

Statistical treatment of biotic information including chlorophyll a, phytoplankton and zooplankton biomass resulted in the definition of four clusters (Figure 14). Cluster 1 included Elliot and Unnamed Lakes; Cluster 2 contained both Esten Lake basins; Cluster 3 included Depot Lake and McCarthy basin 1, while Cluster 4 was made up of Nordic Lake along with basins 2 and 3 of McCarthy Lake.

Except for the grouping of Unnamed Lake with Elliot Lake, this clustering strategy was coincident with known responses to the input of nutrients or mining-milling discharges. The unexpected grouping of Unnamed Lake with Elliot Lake might be explained partly by the lower sampling frequency applied to the B category lakes. In the remaining groups, Esten Lake, which was characterized by the high order of primary biological activity associated with nutrient enrichment, was grouped separately from the less productive basins of Depot Lake and basin 1 of McCarthy Lake.

The fourth biotic factor grouping of Nordic Lake and McCarthy Lake basins 2 and 3 reflected the influence of mining-milling activities and represented both oligotrophic conditions and the presence of high concentrations of inorganic nitrogen.

Results of principal components analysis for chemical data (Figure 15) show two clumped groupings of lakes with a linear gradient for the third group.

Factor 1 loads on alkalinity, total inorganic carbon and pH. It explains 48.1% ($\lambda = 3.37$) of the variance in the dataset. This factor is weighted on chemical parameters that can be related with primary production-associated fluxes.

Factor 2 loads on conductivity, sulphate and inorganic nitrogen. It explains 37.6% ($\lambda = 2.63$) of the variance. This factor is weighted on parameters associated with the mining-milling activity of the Serpent River basin.

Group 1 consists of Elliot Lake Stations 1 and 2 while group 2 represents Nordic Lake Stations 1 and 2, and the Unnamed Lake immediately downstream. The remaining seven stations lie along a line from Esten Lake Station 1 to McCarthy Lake Station 3. This linear response reflects the primary and secondary production gradient established by the biotic data for the Esten to McCarthy Lake chain. It suggests a gradation of response to nutrient addition at Esten Lake and the assimilation and dilution of the nutrient supply through the river system. The influence of mining-milling chemical components is expressed at the McCarthy Lake Station 2 and 3 end.

Overall, the multivariate statistical treatments including the clustering and principal components analysis result in a similar ordering of lake basins. This order can be explained in terms of response to nutrient loading factors or the influence of industrial discharges which include the inorganic nitrogen component.

All three datasets suggest that McCarthy Lake's Station 1 is in a state of transition between the influence of the phosphorus enriched Esten-Depot arm and the inorganic nitrogen rich main flow of the Serpent River.

The relationship of inorganic nitrogen in study lake basins with common trophic status indicators was investigated through the development of a correlation matrix (Table 4).

Table 4

CORRELATION MATRIX FOR MEAN VALUES OF
COMMON TROPHIC STATUS INDICATORS

	S.D.	Chloro <u>a</u>	Phyto	Zoo	TP	IN
	1	2	3	4	5	6
1	1.000					
2	<u>-0.897</u>	1.000				
3	<u>-0.862</u>	<u>0.873</u>	1.000			
4	-0.346	0.212	0.083	1.000		
5	<u>-0.689</u>	<u>0.754</u>	<u>0.898</u>	-0.110	1.000	
6	<u>0.745</u>	<u>-0.640</u>	<u>-0.576</u>	<u>-0.655</u>	-0.367	1.000

 = 0.05, 0.576

 = 0.01, 0.708

S.D. - Secchi disc visibility

Chloro a - chlorophyll

Phyto - phytolankton biomass

Zoo - Zooplankton biomass

TP - total phosphorus

IN - inorganic nitrogen

Traditional correlations between trophic status indicator parameters held true.

Water clarity, as measured by Secchi disc visibility (S.D.) was negatively correlated with chlorophyll a, phytoplankton biomass and total phosphorus concentration. A positive correlation was obtained between Secchi disc visibility and inorganic nitrogen concentration.

Chlorophyll a, a surrogate measure of phytoplankton density was positively correlated with phytoplankton biomass and total phosphorus. It was negatively correlated with inorganic nitrogen concentration.

Phytoplankton biomass was positively correlated with total phosphorus and negatively correlated with inorganic nitrogen concentration.

Although zooplankton biomass values were found to be of limited use in the evaluation of lake trophic status, a negative correlation with inorganic nitrogen concentration was observed.

Total phosphorus was found to be negatively correlated with water clarity in the study lakes but was strongly correlated with the primary indicators of trophic activity, chlorophyll a and phytoplankton biomass.

Inorganic nitrogen was negatively correlated with trophic status indicators.

SUMMARY DISCUSSION

The purpose of this study was to evaluate the eutrophication potential of the high nitrate/ammonia supply to the waters of the Serpent River system from the uranium mining-milling industry. This problem was investigated in part, by the evaluation of the trophic status of lakes within the Serpent River which were receiving different combinations of nutrients from a variety of sources.

The designation of trophic status is generally achieved by the classification of lakes into three distinct trophic categories including oligotrophic, mesotrophic and eutrophic. This classification is often subjective since clear boundaries between the categories are not identifiable. Variation and weakness of correlation among the individual parameters used to define trophic status further complicate classification into distinct categories.

In recent times, the mean ice free or spring turnover period total phosphorus concentration has found prominence in the estimation of trophic category (Dillon and Rigler 1975). More recently, a probabilistic approach to trophic designation by phosphorus concentration has been proposed (Vollenweider and Kerekes 1980). They have suggested that lakes with total phosphorus concentrations equal to 15 ug/L have an equal probability of being oligotrophic or mesotrophic.

When this equivalence concentration is used to assign the Serpent River study lakes or their basins to trophic states, the following categorization results.

Esten Lake with the highest lakewide concentration of total phosphorus at 47 ug/L is classified as eutrophic since its mean ice free phosphorus concentration is much in excess of 15 ug/L .

Mesotrophic categorizations are assigned to both Depot Lake basins with phosphorus means of 15 and 20.7 ug/L. Unnamed Lake also falls into the mesotrophic class with a total phosphorus concentration of 17.5 ug/L but the validity of the value is questionable as a result of a low sampling frequency and apparently anomalous data.

Oligotrophic classifications are indicated for Nordic, McCarthy, the two lakes with the highest inorganic nitrogen concentrations, and Elliot Lake where mean total phosphorus concentrations remained less than 15 ug/L.

When the remaining study component parameters having a bearing on the classification of trophic status are included in the determination of each lake's or basin's degree of biological productivity, the following classifications are achieved.

Esten Lake

Esten Lake with a low N:P ratio of 6:1 remains classified as an eutrophic waterbody. On a relative scale of biological productivity within the lakes of the western arm of the Serpent River, Esten Lake is the most productive. Chlorophyll a concentrations are high (greater than 13 ug/L) and are accompanied by poor Secchi disc visibilities (3.5m). Phytoplankton densities are also considered high, ranging between 3 and 5 mm³/L. The phytoplankton community has the

highest diversity of algal genera (63) and most representatives in the Chlorophycean and Cyanophycean groups. The dominance of the community by the Chlorophyceae and the appearance of a late summer bloom of the Cyanophycean Anabaena are indicative of nutrient enrichment or conditions induced by nitrogen and phosphorus fertilization (Schindler and Fee 1974, Findlay 1978, Dillon et al 1978).

Although zooplankton biomass has recently been related to trophic status (M.O.E. 1983) this relationship did not apply to Esten Lake. Likewise, benthic organism collection was of little use in determining trophic status.

Monitoring of vertical dissolved oxygen distribution for Esten Lake revealed the development of the clinograde profile associated with conditions of nutrient enrichment. Areal hypolimnetic oxygen deficits in both basins also indicated productive conditions.

Depot Lake

Depot Lake displayed an N:P ratio of approximately 9:1 and was classified as a mesotrophic waterbody. A higher order of biological productivity was indicated for the shallow eastern basin. Chlorophyll a concentrations were approximately 3 and 5 ug/L while Secchi disc visibilities were 5.5 and 4.8m at Stations 1 and 2 respectively. Phytoplankton densities were moderate at between 1 and 2mm³/L supporting the mesotrophic classification.

The phytoplankton community exhibited good diversity with a total of 58 genera common to Depot Lake. Chrysophycean dominance was apparent over the sampling period although

signs of enrichment through an Anabaena dominated Cyanophycean bloom were detected at Station 2 in July.

Zooplankton biomass was relatively high in comparison to the other sampling locations while benthic samples failed to provide useful data for trophic classification.

Dissolved oxygen profiles were affected by basin depth, but both basins were characterized by clinograde distributions associated with conditions of nutrient enrichment.

A.H.O.D. determinations suggested moderate levels of biological productivity.

McCarthy Lake Station 1

Although probabilistic classification on the basis of mean total phosphorus concentration suggested oligotrophy for the McCarthy Lake basins, analysis of biotic components indicated a mesotrophic status at Station 1 near the inflow from Depot Lake.

A high nitrogen to phosphorus ratio of 154:1 reflected the influence of the inflowing main branch of the Serpent River. The moderately high, mean chlorophyll a concentration of 5 ug/L and Secchi disc visibility average of 5.3m supported a mesotrophic degree of productivity as did the moderate phytoplankton biomass.

The phytoplankton community revealed good diversity with 55 genera identified. Successional class composition was different from that of the other McCarthy Lake basins in the summer with dominance by a Chlorophyte-Dinophyte assemblage suppressing the oligotrophy associated Chrysophyte group.

On a relative scale, zooplankton biomass was moderate.

The dissolved oxygen profile was the clinograde mesotrophic type, but its shape was influenced by shallow basin depth and low hypolimnetic volume. Nevertheless, the onset of the clinograde vertical oxygen distribution early in the period of thermal stratification was suggestive of an enriched biological environment. The hypolimnetic oxygen deficit suggested oligotrophy but was influenced by shallow basin depth.

Nordic Lake

When biotic and physical measurements of trophic status were included in the classification of Nordic Lake, the probabilistic categorization of oligotrophy held true.

Due to the input of inorganic nitrogen by the Buckles Creek drainage, the N:P ratio in Nordic Lake remained high at 240:1. Primary biological activity was very low with chlorophyll a concentrations less than 1 ug/L and phytoplankton biomass less than 0.3 mm³/L. Secchi disc visibility was very good with a sampling mean exceeding 6.5m.

Although the phytoplankton flora was diverse exhibiting 52 genera, the sparse biomass was dominated by Bacillariophycean and Chrysophycean groups. The bloom forming Cyanophycean Anabaena which is associated with nutrient enrichment conditions, was not isolated from the Nordic Lake planktonic community. Zooplankton biomass was low in relation to other study basins.

Although dissolved solids meromixis existed in one basin, dissolved oxygen and temperature profiles exhibited a favourable positive heterograde oxygen distribution indicative of a low order of biological productivity.

Areal hypolimnetic oxygen deficits for both basins were extremely low suggesting oligotrophy.

McCarthy Lakes Stations 2 and 3

Stations 2 and 3 on McCarthy Lake were also classified as oligotrophic when all trophic status indicators were involved in the evaluation.

Nitrogen to phosphorus ratios of 216:1 and 337:1 respectively were high accenting the availability of inorganic nitrogen. Primary biological activity was very low with mean chlorophyll a concentrations the lowest encountered and phytoplankton biomass less than $0.3 \text{ mm}^3/\text{L}$. Water clarity was excellent averaging 8m at Station 2 and 7m at Station 3 of McCarthy Lake.

Although the numbers of individuals in the phytoplankton community were limited, the flora was diverse with 48 and 52 genera recorded. The Chrysophyceae, which are associated with oligotrophic conditions when present as ice-free period class dominants in excess of 40%, remained important components of the flora throughout the sampling period. As in Nordic Lake, the Cyanophycean Anabaena was not found.

Zooplankton biomass at $1.6 \text{ ug}/\text{m}^3$ was among the lowest recorded for the study lakes.

Dissolved oxygen profiles were indicative of oligotrophic conditions also, since persistence of the orthograde distribution through most of the period of thermal stratification was apparent.

Areal hypolimnetic oxygen deficits were confusing at McCarthy Lake's far basins. Although both basins revealed deficits associated with oligotrophic conditions, the relative deficit for Station 2 ($184 \text{ mg O}_2 \text{ m}^{-2} \text{ d}^{-1}$) was not consistent with the low order of primary biological activity indicated by the chlorophyll a and phytoplankton data.

Elliot and Unnamed Lakes

The B study lakes, Elliot and Unnamed were also classified as oligotrophic waterbodies on the basis of the water quality parameters examined; however, the confidence level of the classification was lower than for the A lakes due to a lower frequency of sampling.

Elliot Lake's nitrogen to phosphorus ratio was 29:1. A tendency toward a mesotrophic classification for Station 2, the basin influenced by urbanization, was observed as chlorophyll a concentrations and phytoplankton biomass values were near the limits used to define this trophic category. Secchi disc visibility approached 6m at Station 1 but was lower (5m) at Station 2.

The phytoplankton communities were dominated by Chrysophyceae and Bacillariophyceae which are characteristic of oligo-mesotrophic conditions. Zooplankton biomass (15.5 ug/m^3) was the highest recorded for the study lakes.

Vertical distribution of dissolved oxygen was orthograde to positive heterograde for the period of stratification with a tendency to clinograde prior to autumn lake turnover. A tendency toward a mesotrophic status was indicated by oxygen deficit calculations for Elliot Lake's basin 2.

Probabilistic classification on the basis of mean phosphorus concentration put Unnamed Lake into a mesotrophic category. However, limnological data support an oligotrophic class for this lake. The nitrogen to phosphorus ratio of 105:1 was high. Chlorophyll a concentrations were less than 2 ug/L while Secchi disc visibility was high (5.8m). The low order of biological productivity was emphasized by very low phytoplankton biomass ($0.24 \text{ mm}^3/\text{L}$). The algal flora was the least diverse of the study lakes with only 30 genera identified, but sampling frequency was likely a determining factor. Bacillariophyceae and Chrysophyceae dominated the phytoplankton community and the Cyanophycean Anabaena was not identified from the samples.

Surprisingly zooplankton biomass (14.8 ug/m^3) was relatively high.

The dissolved oxygen profile was affected by shallow basin depth but a positive heterograde distribution was apparent for a major part of the stratification period suggesting a low oxygen demand by sedimenting organic matter. This was corroborated by low oxygen deficit calculations.

Marshland Grandeur and Trout Lakes

The C study lakes, Marshland, Grandeur and Trout located between Esten and Depot Lake were classified as eutrophic to mesotrophic based on the spring turnover and autumn total phosphorus concentrations detected. Since these lakes were located between the eutrophic Esten and the mesotrophic Depot Lake, a downward gradation in trophic status with distance from Esten Lake would be a reasonable assumption.

Inorganic Nitrogen and Trophic Status

When the classical approach to the determination of trophic status was applied to lakes in the Serpent River Basin, it was found that basins containing high concentrations of inorganic nitrogen alone and having high N:P ratios were classified as oligotrophic. Included in this category are Nordic, McCarthy (basins 2 and 3) and Unnamed Lakes. These lakes were characterized by a very low order of biological productivity expressed as low chlorophyll a concentrations, phytoplankton biomass and relatively low oxygen demand in their hypolimnetic zones.

On the other hand, where the nutrient element phosphorus was also available, as in Esten Lake and those lakes through which the Esten Lake discharge maintained its chemical influence, eutrophic to mesotrophic conditions persisted. Biological productivity indicators revealed active to moderately active trophic states.

Through the classification of the Serpent River study lakes into trophic states and by the relation of these trophic states to the concentration of available inorganic nitrogen, it is apparent that nitrates/ammonia in the Serpent River

System do not in themselves promote eutrophication. Those lakes with the highest availability of inorganic nitrogen, displayed the lowest degree of trophic activity.

The only lake basin exhibiting a high N:P ratio (154:1) to be classified as mesotrophic was McCarthy Lake's Station 1. However, the moderate degree of primary biological activity indicated by chlorophyll a and phytoplankton biomass values was attributed to the availability of phosphorus (13.6 ug/L) originating in the discharge from the mesotrophic Depot Lake. Shallow basin depth, hence warmer water temperatures through the trophogenic zone could also have been a factor in the mesotrophic trophic status classification.

The application of multivariate statistical techniques to biotic and chemical data obtained during this study resulted in the common separation or grouping of lake basins. Three broad categories were identified including: (a) control basins, (b) nutrient impacted basins, and (c) mining- milling influenced basins.

The nutrient impacted basins included Esten, Depot and basin 1 of McCarthy Lake. Nordic, Unnamed and basins 2 and 3 of McCarthy Lake were allocated to the category affected by mining-milling factors where inorganic nitrogen was a major component. Basin 1 of McCarthy Lake was in a transition state between the two categories.

With respect to trophic status classification, the lake basin breakdown achieved through the statistical data analysis separates lakes into groups easily associated with either phosphorus enrichment or with the presence of high concentrations of inorganic nitrogen. This result strongly suggests that the inorganic nitrogen component by itself is not the driving factor in the determination of trophic status within the Serpent River System.

The development of a correlation matrix for inorganic nitrogen and trophic status indicators diminishes further the relationship between nitrogen and eutrophication. The positive correlation of inorganic nitrogen with water clarity, a sign of low biological productivity, and the negative correlation of nitrogen with the direct trophic status indicators; chlorophyll, phytoplankton and zooplankton reinforces the conclusion that nitrates/ammonia in the Serpent River System are not eutrophication agents. However, when phosphorus is also available, as in Esten Lake, the presence of nitrogen enhances biological productivity. Through the influence of biological nitrogen uptake and assimilation, the aquatic nitrogen to phosphorus ratio is reduced (less than 10:1) and nitrogen can become a limiting factor. The addition of nitrogen to a lake limited by nitrogen availability but with ample phosphorus supplies can lead to symptoms of eutrophication.

The future significance of high nitrate/ammonia concentrations as factors in the promotion of eutrophication within the Serpent River System will focus in Depot Lake and the McCarthy Lake basins.

In 1981, the two basins of Depot Lake exhibited characteristics of mesotrophy while McCarthy Lake's Station 1 was in a transition state of trophic activity. McCarthy's Stations 2 and 3 remained oligotrophic. The water quality of these five basins was expected to be influenced by the increased phosphorus loadings from the short circuiting of the Town of Elliot Lake's sewage plant effluent. In McCarthy Lake the continued presence of high inorganic nitrogen concentrations could promote a shift in trophic status when coupled with the increased phosphorus load from Depot Lake.

Whether problematic eutrophication occurs in the far basins of McCarthy Lake and the downstream waters of the Serpent to the Serpent River Harbour area, is dependent on the magnitude of the phosphorus loading from Depot Lake and the nutrient assimilative abilities of the downstream waters.

Empirical Modeling of Phosphorus Loading

The potential effects of phosphorus loading to the Serpent River System can be examined through the use of empirical models. Although numerous models are available to examine the interaction of phosphorus loading and lake response, the approaches of the Lakeshore Capacity Study, (MOE, 1983) and Reckhow and Chapra (1983) were used.

The Lakeshore Capacity approach, which is an advanced version of the Dillon (1974) model, was considered the weaker of the two approaches. It had been developed primarily for oligotrophic lakes. The magnitude of phosphorus loading expected here could exceed the experimental limits of the model. Less confidence would be placed in the model predictions.

The Reckhow models were developed on a wide range of lake trophic states and could be adjusted to conform to the flow conditions found in the Serpent River System.

The Nordic-Esten Lake diversion and the commissioning of the sewage treatment plant were completed in December 1981. However, the expansion of the townsite into the Nordic and Esten Lake watersheds proceeded through 1982-83. In 1984, conditions were stable. Model predictions based on stable environmental data represent existing conditions with greater confidence. For this reason, modeling of phosphorus supply was based on 1984 monitoring data. Models were developed to follow the movement of sewage plant phosphorus through: (a) the diversion area, (b) Depot Lake and (c) McCarthy Lake. Model results are listed in Table 5.

TABLE 5

PHOSPHORUS RESPONSE MODELING

LAKE	PHOSPHORUS LOAD g/m ² /yr	AREAL WATER LOAD qs	LAKESHORE CAPACITY	PREDICTED PHOSPHORUS CONCENTRATIONS mg/m ³	
				RECKHOW	RECKHOW qs>50
Diversion	11.85	48.9	202	198	189
Depot	2.36	59.4	37	-	27
McCarthy	1.14	71.7	14	-	-
	0.98		-	-	10
Model Inputs: - Flow from sewage plant				4.2 x 10 ⁶ m ³ /yr	
- Sewage effluent P				0.8 mg/L	
- Nordic Lake outflow P				0.008 mg/L	
- Watershed P supply				5.5 mg/m ² /yr	
- Precipitation P				37.3 mg/m ² /yr	
- Trout Lake outflow P				0.015 mg/L	
- Serpent River (Pecors Lk) P				0.008 mg/L	
- Anoxic Hypolimnion Depot Lk				-	

The Lakeshore Capacity model predicted higher average phosphorus concentrations for all three water bodies than did the Reckhow model. However, predictions were relatively similar.

Hypereutrophic conditions were forecast for the diversion area by both models. In Depot Lake, the Lakeshore Capacity model predicted eutrophic conditions. The Reckhow model predicted phosphorus concentrations associated with mesotrophic conditions. Most of the phosphorus from Depot Lake was expected to be assimilated through McCarthy Lake. Oligo-mesotrophic phosphorus concentrations were predicted in the outflow from McCarthy Lake.

Because there is a long stretch of river between McCarthy Lake and Serpent Harbour, including additional lake basins, further reduction and dilution of phosphorus concentrations is expected. The potential for eutrophication problems in the Serpent Harbour area is very low.

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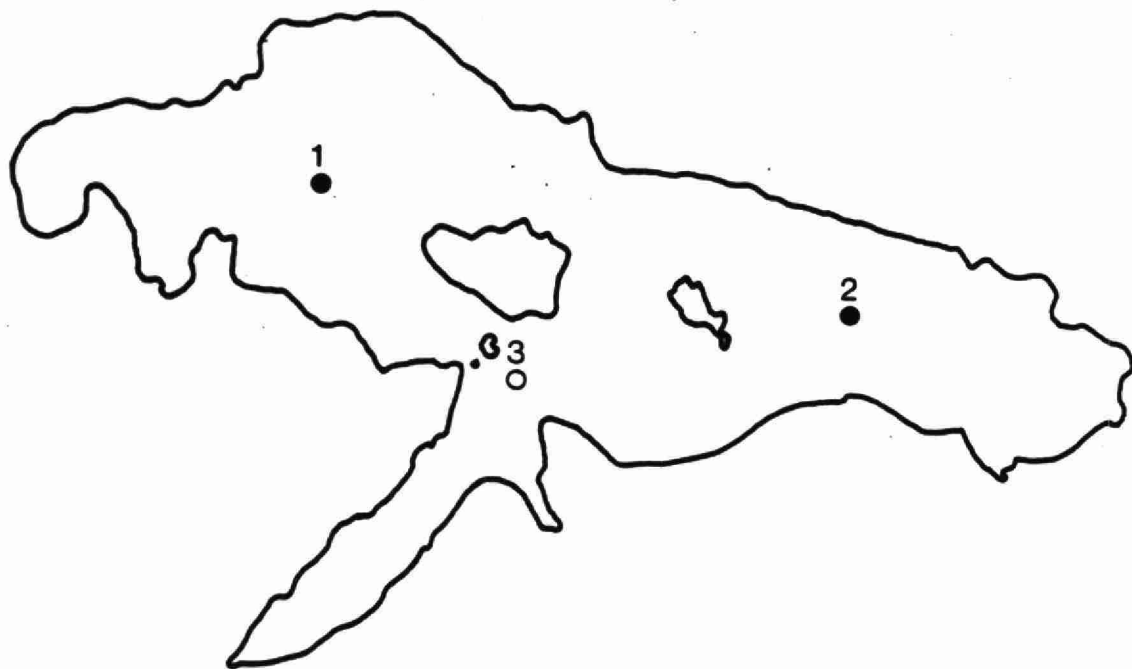
APPENDIX I
SAMPLING LOCATIONS

FIGURE 1

NORDIC LAKE SAMPLING LOCATIONS 1981

●- **Primary Station**

○- **Secondary Station**



Scale
0 $\frac{1}{2}$
km

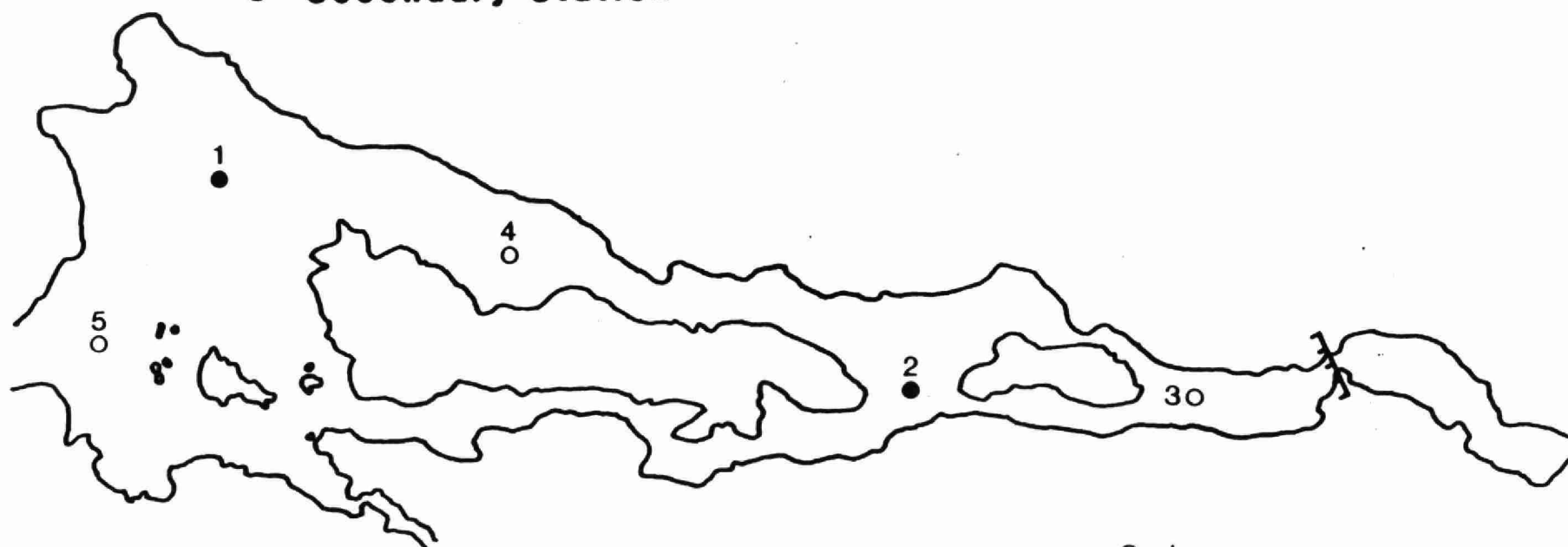
FIGURE II

ESTEN LAKE SAMPLING LOCATIONS

1981

● - Primary Station

○ - Secondary Station



Scale

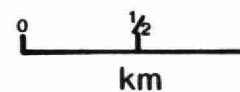


FIGURE III

DEPOT LAKE SAMPLING LOCATIONS

1981

●- Primary Station

○- Secondary Station

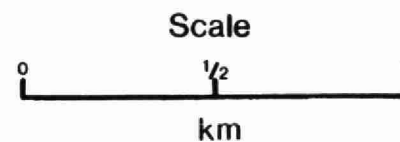
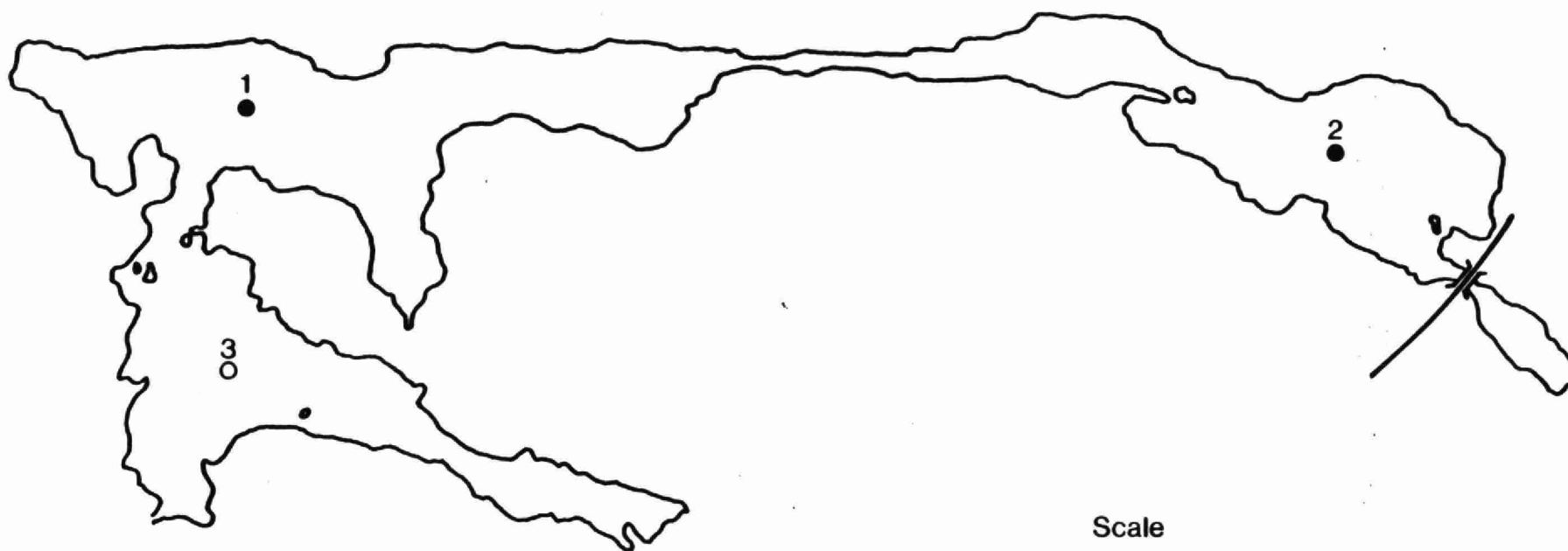


FIGURE IV

**McCARTHY LAKE SAMPLING LOCATIONS
1981**

● - Primary Station

○ - Secondary Station



Scale
0 $\frac{1}{2}$ 1
km

FIGURE V

**UNNAMED LAKE SAMPLING LOCATION
1981**

●- Primary Station

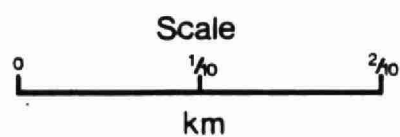
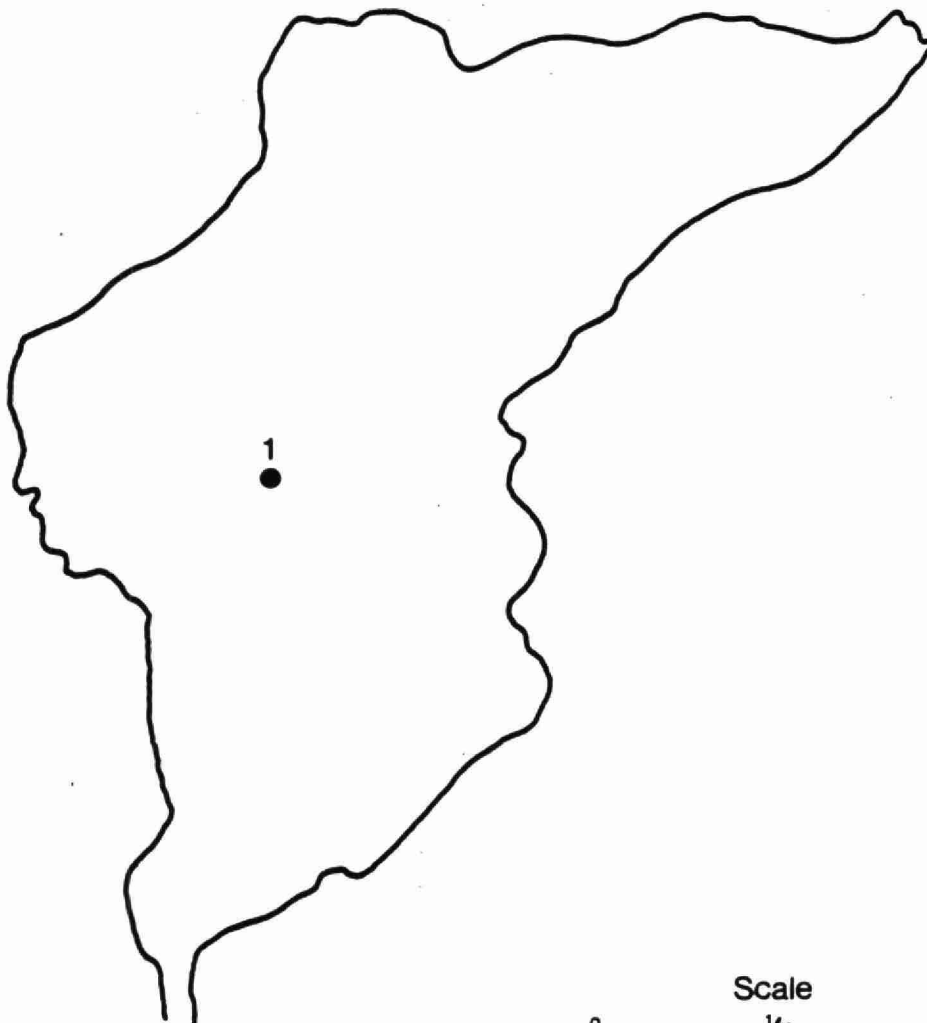
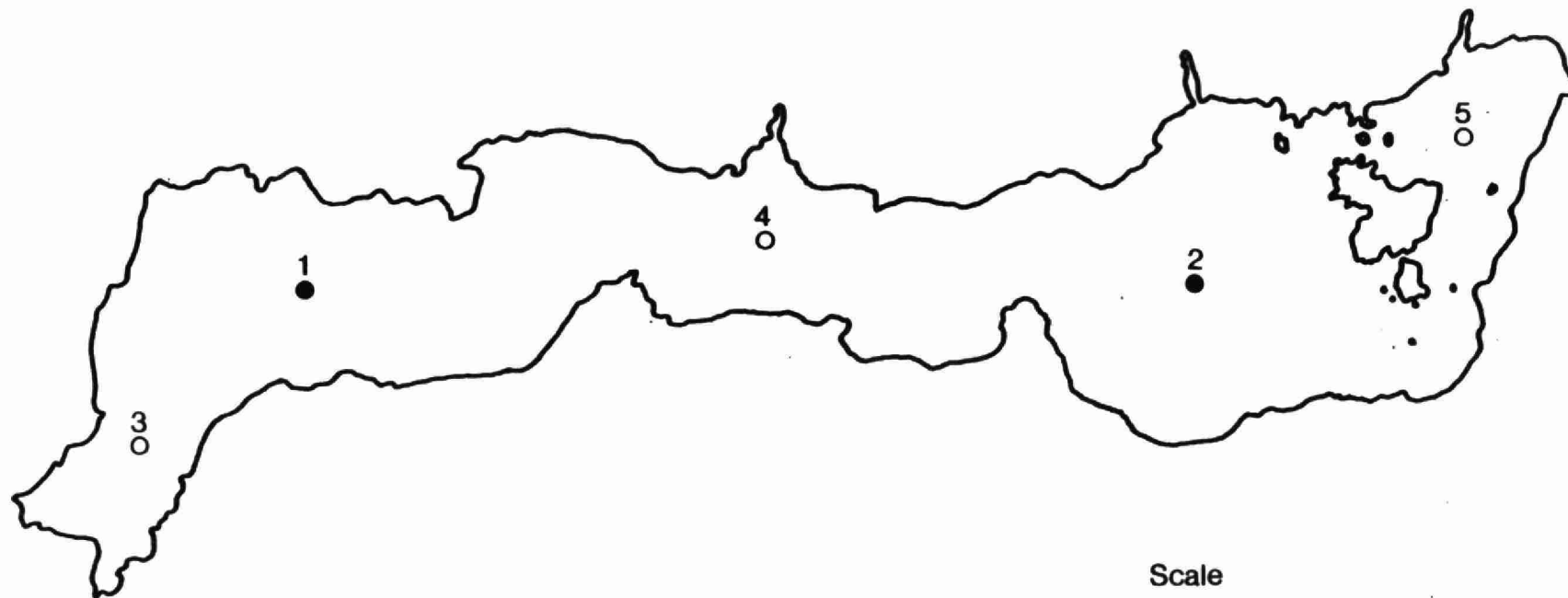


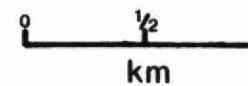
FIGURE VI
ELLIOT LAKE SAMPLING LOCATIONS
1981

●- Primary Station

○- Secondary Station



Scale

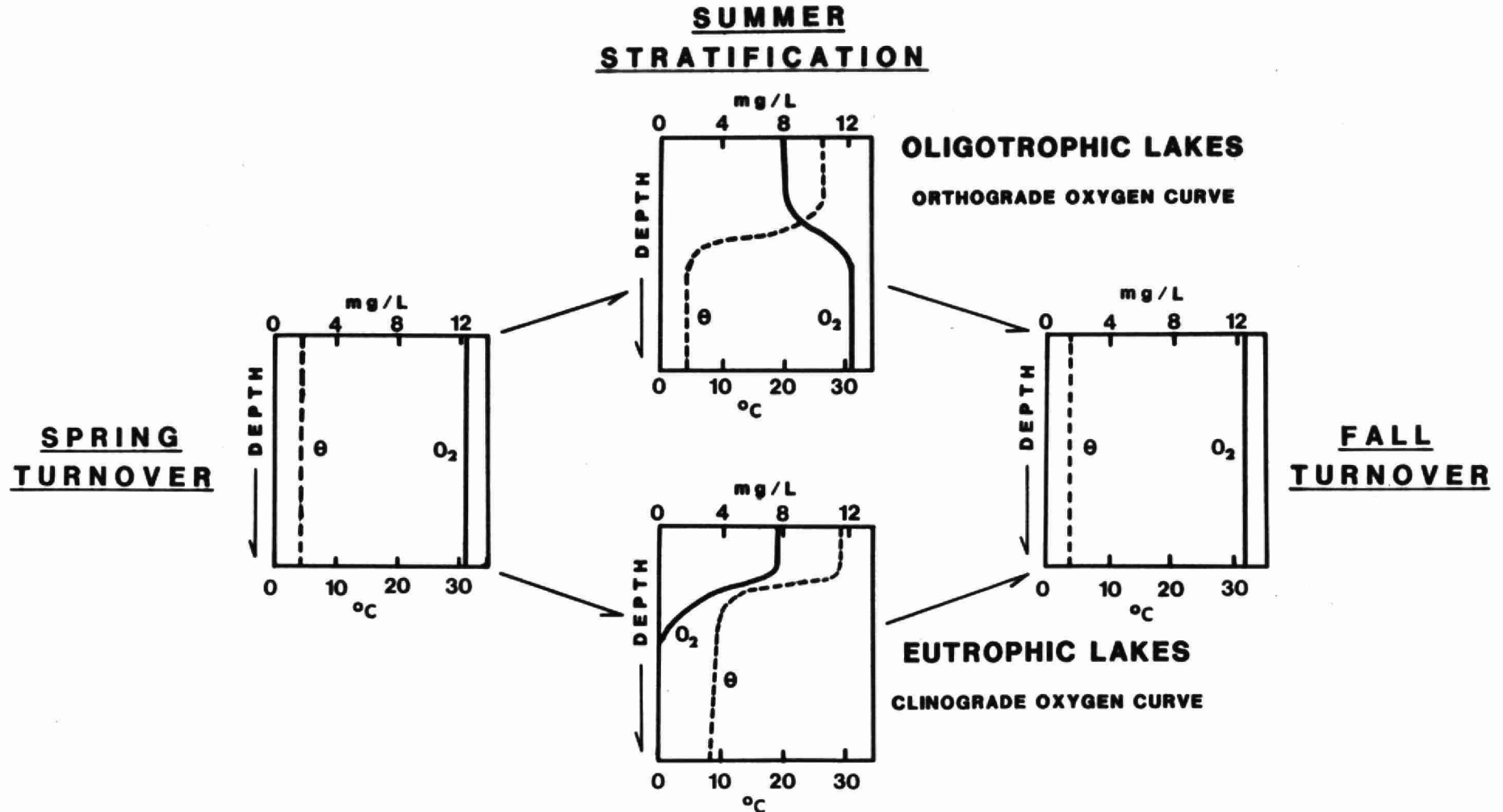


APPENDIX II

DISSOLVED OXYGEN - TEMPERATURE DISTRIBUTIONS
IN NORTHERN TEMPERATE LAKES

OXYGEN - TEMPERATURE VERTICAL PROFILES

Dissolved Oxygen-Temperature Distributions in Northern Temperate Lakes



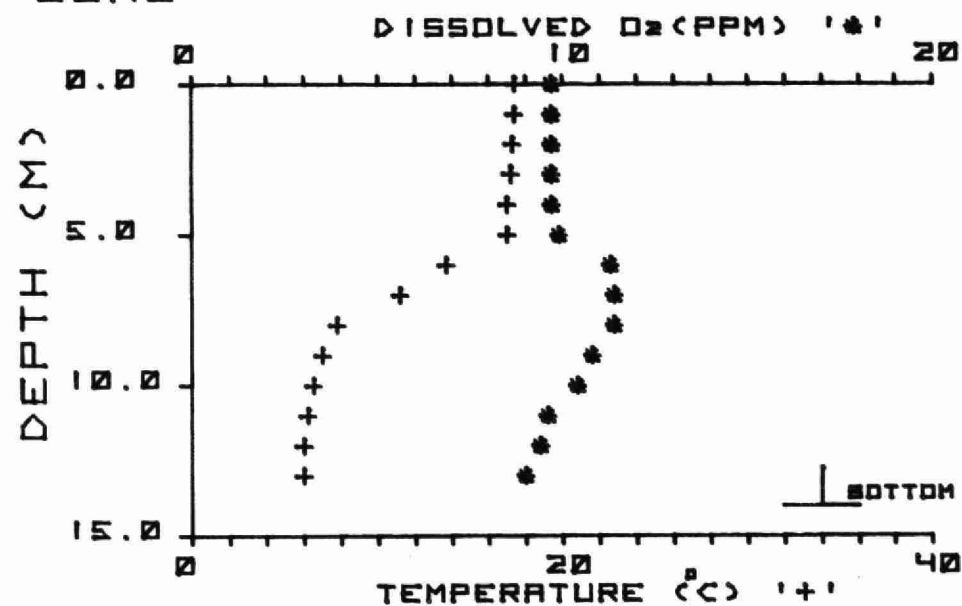
θ - Temperature
O₂ - Dissolved Oxygen

(Modified from Wetzel, 1975)

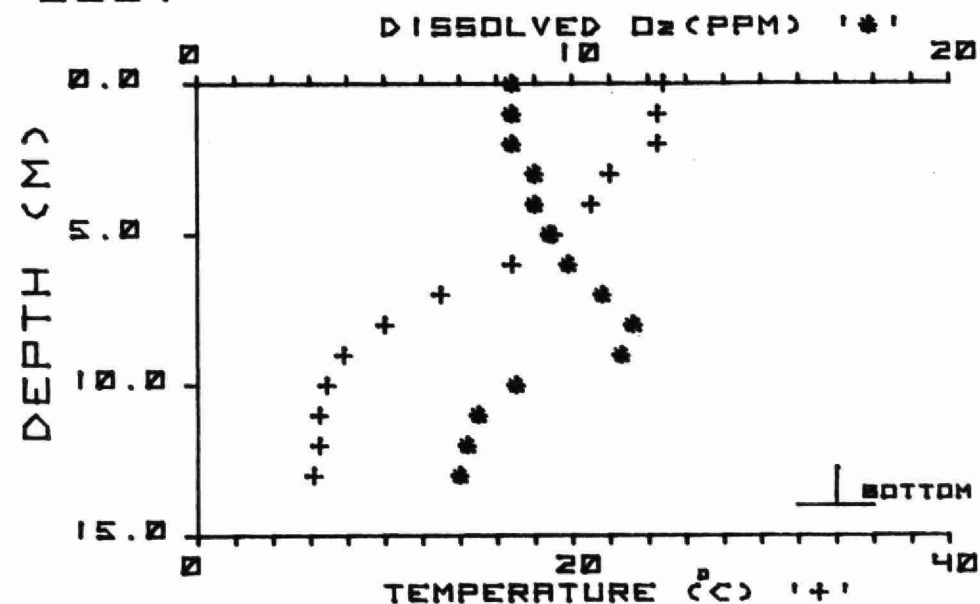
NORDIC LAKE STN. 1

NORTHEASTERN REGION - M.O.E. SUMMER 1981

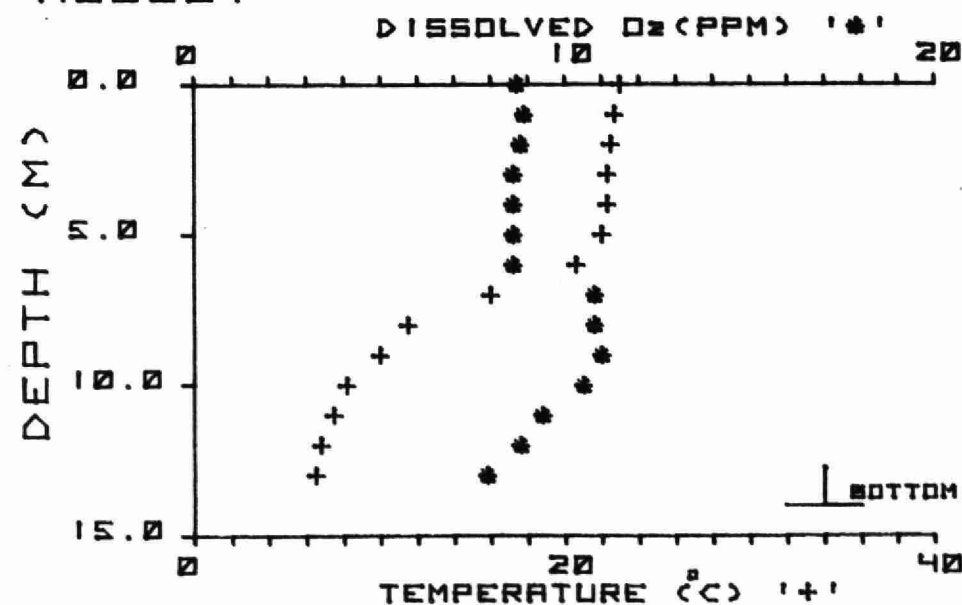
JUNE



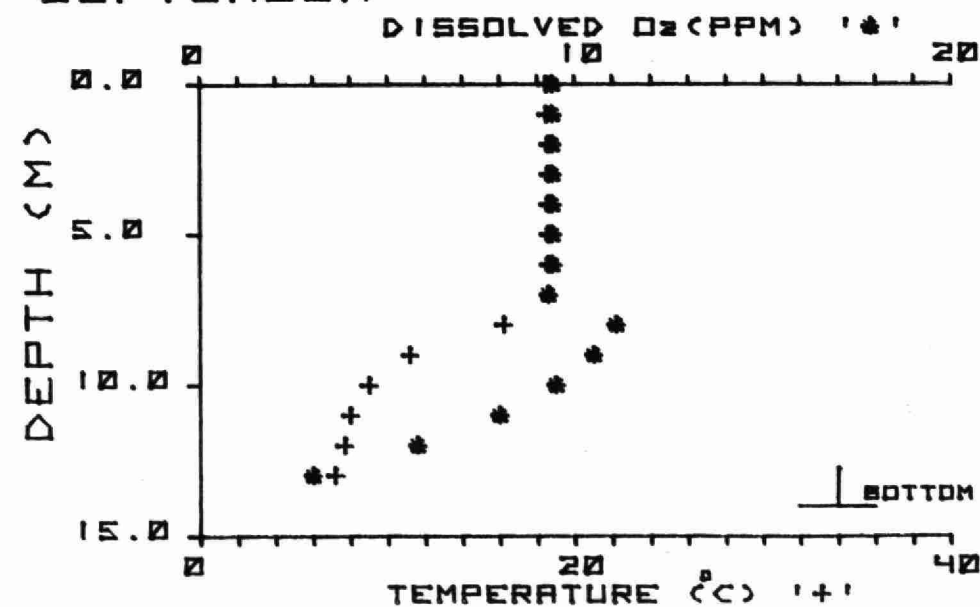
JULY



AUGUST



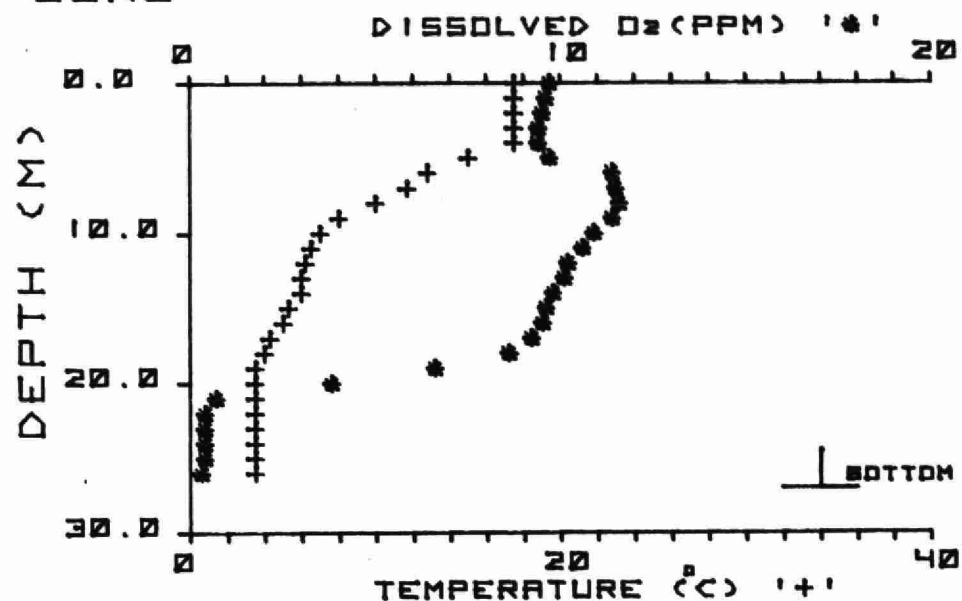
SEPTEMBER



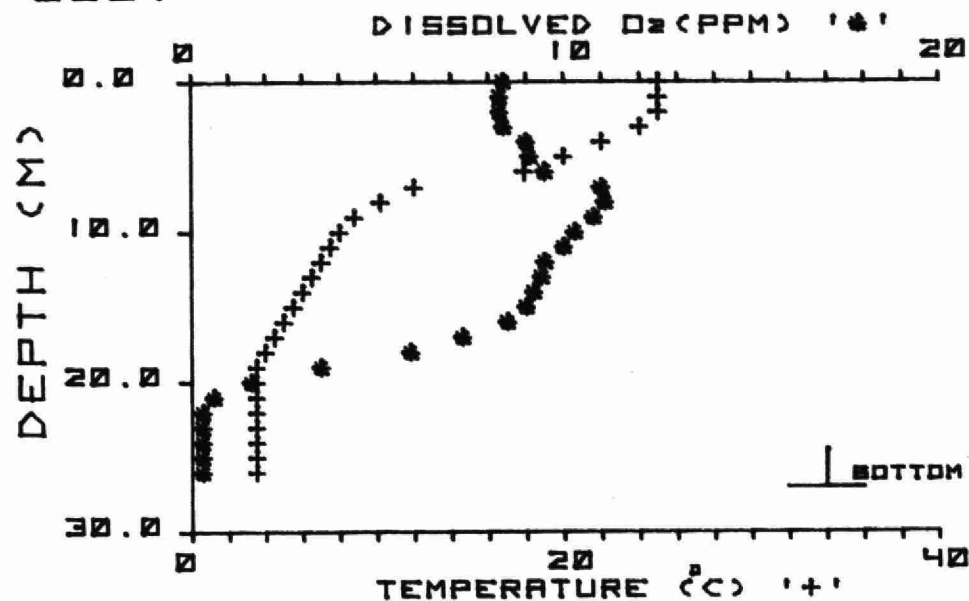
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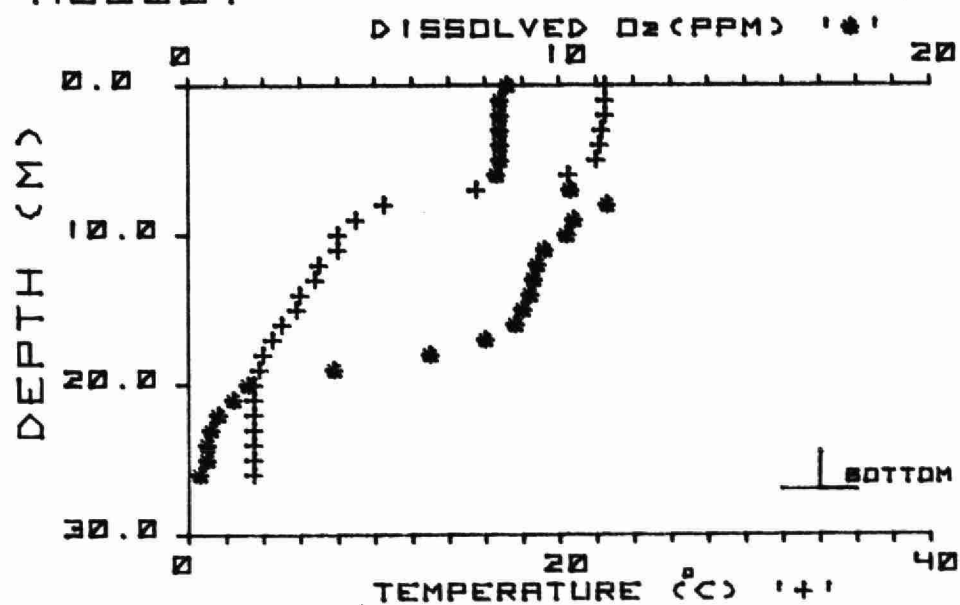
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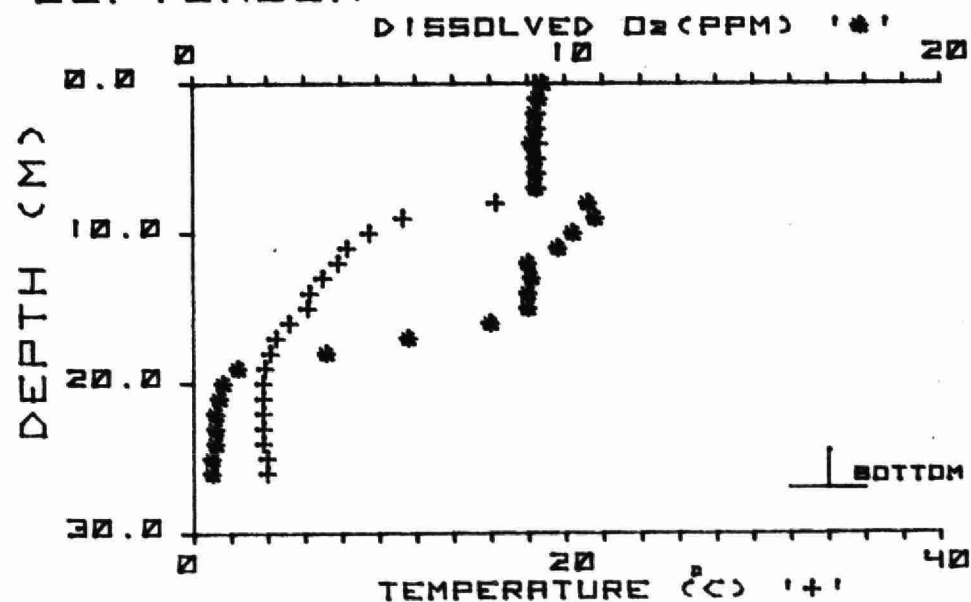
JULY



AUGUST



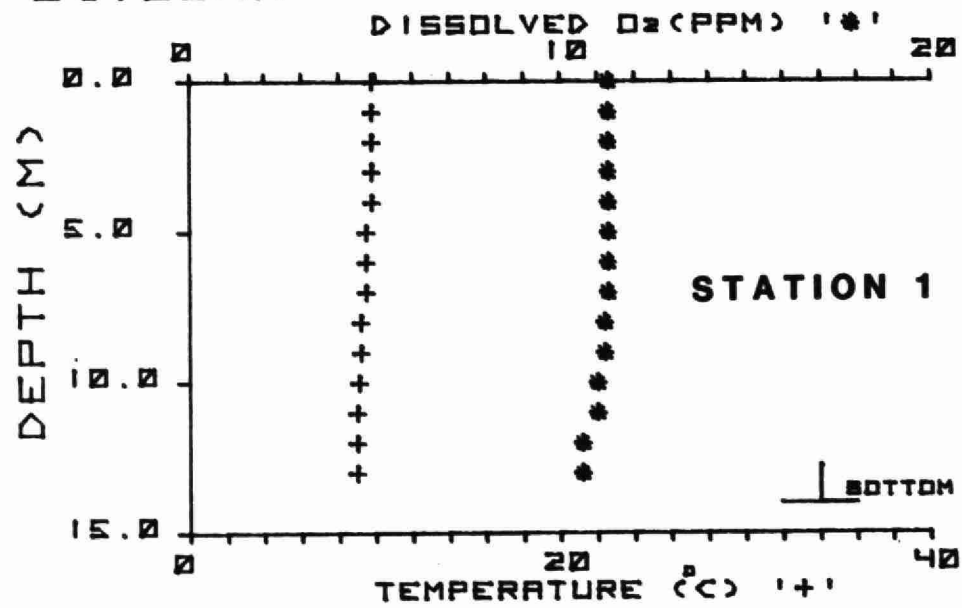
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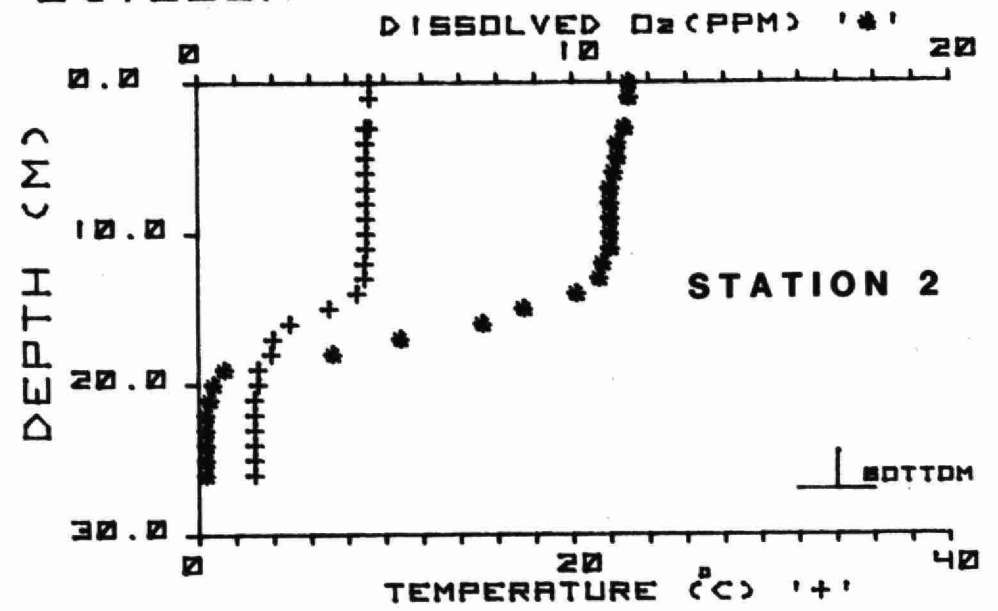
NORDIC LAKE

NORTHERN REGION - M.O.E. SUMMER 1981

OCTOBER



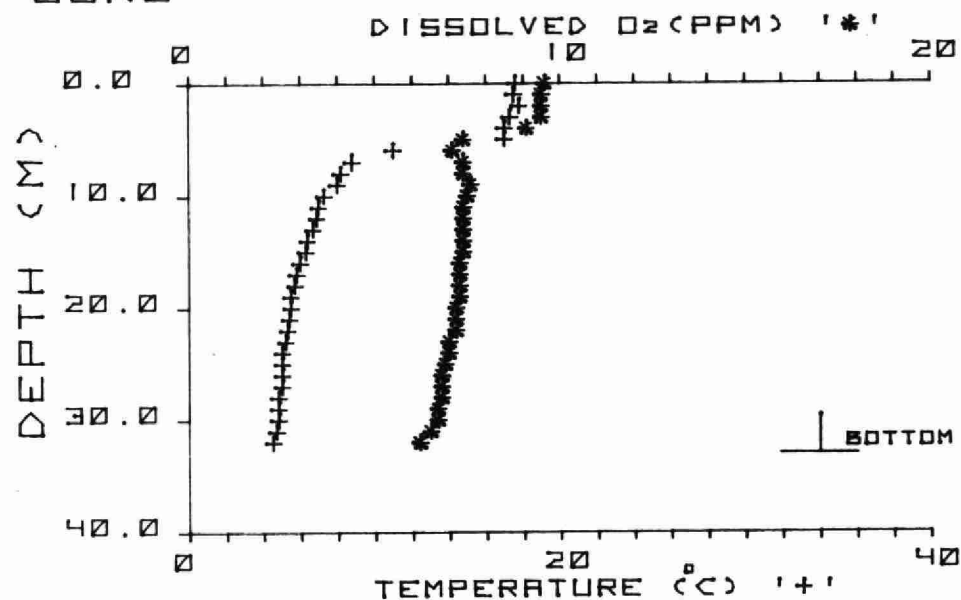
OCTOBER



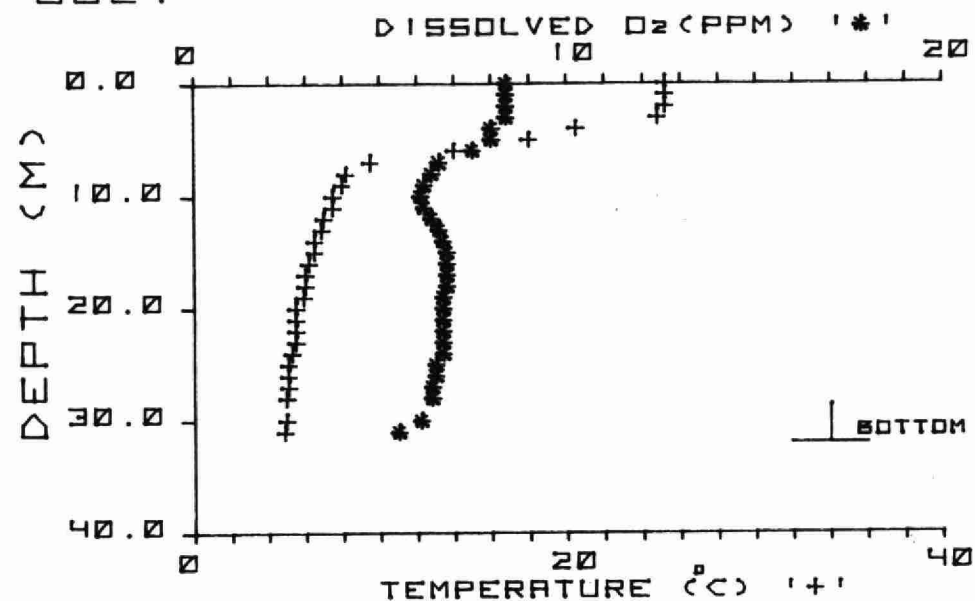
ESTEN LAKE STN. 1

NORTHEASTERN REGION - M.O.E. SUMMER 1981

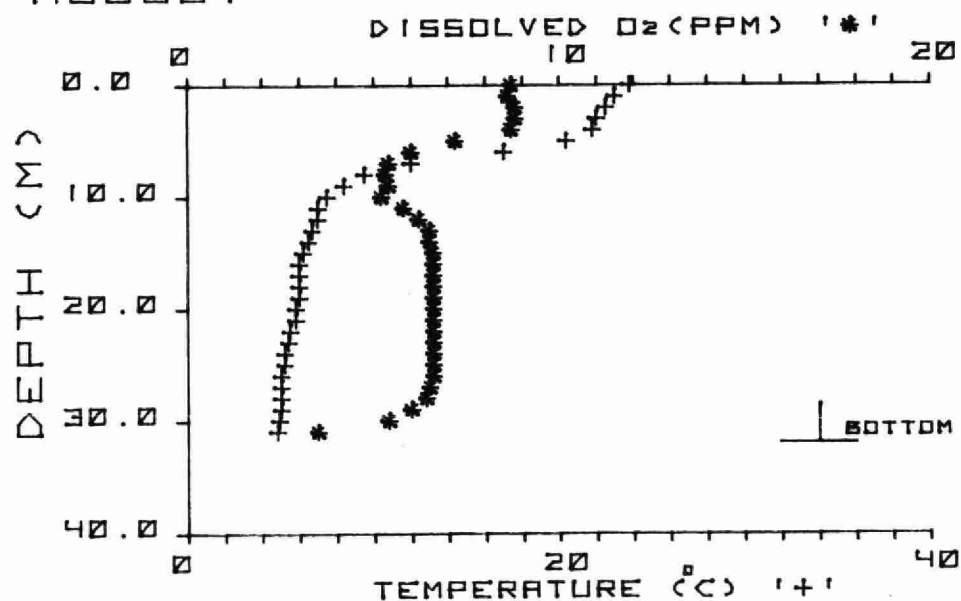
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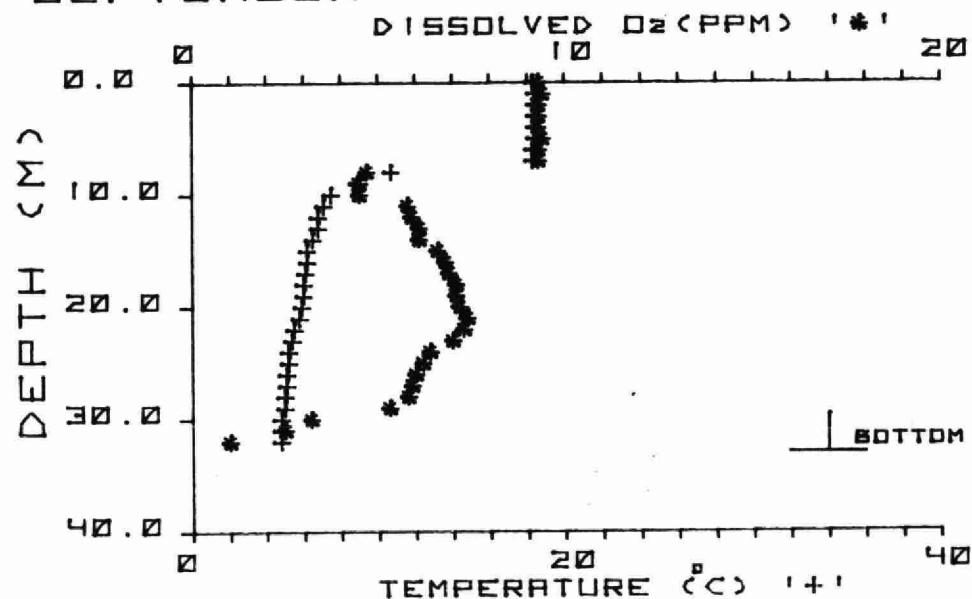
JULY



AUGUST



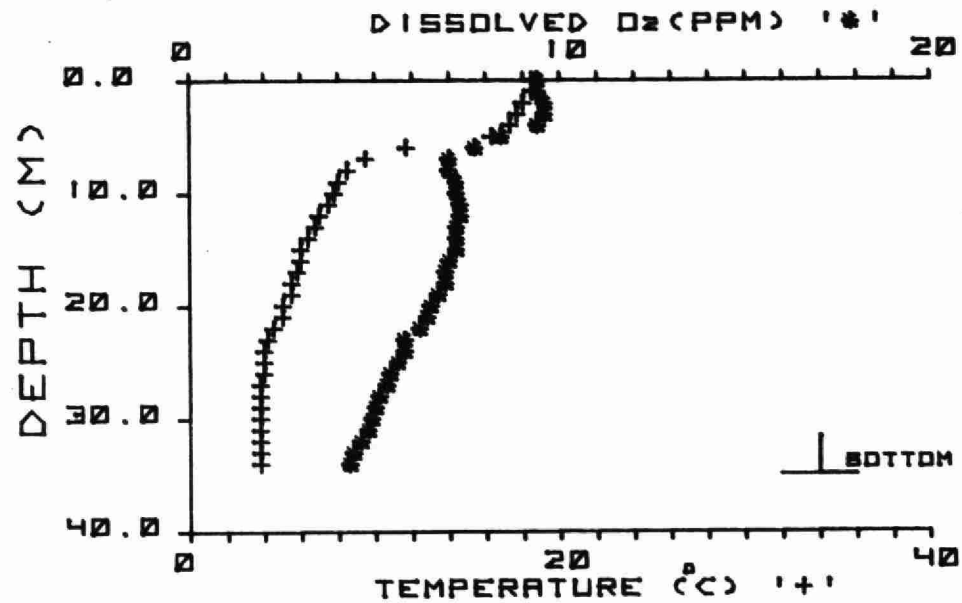
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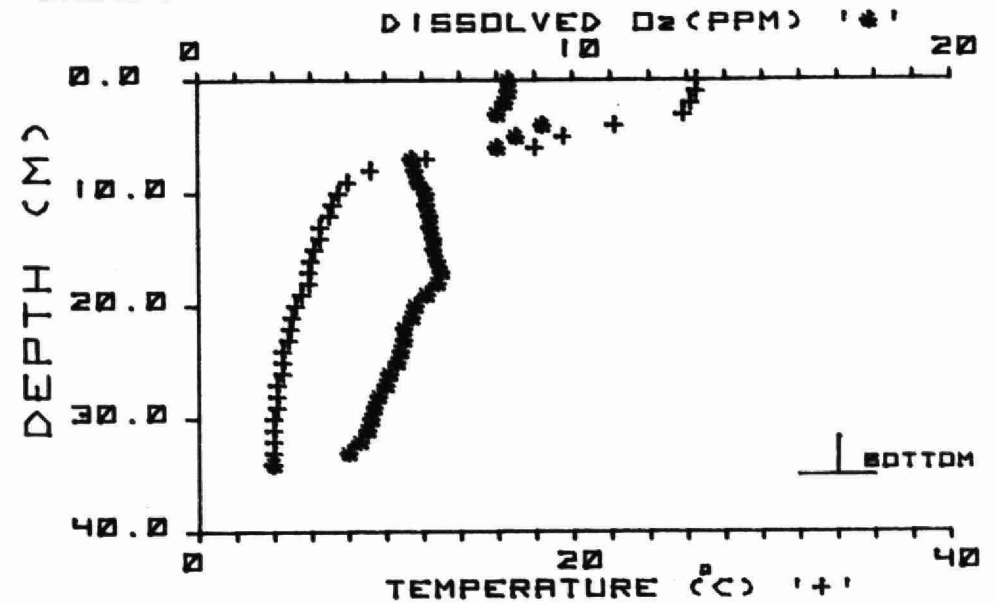
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NORTHEASTERN REGION - M.O.E. SUMMER 1981

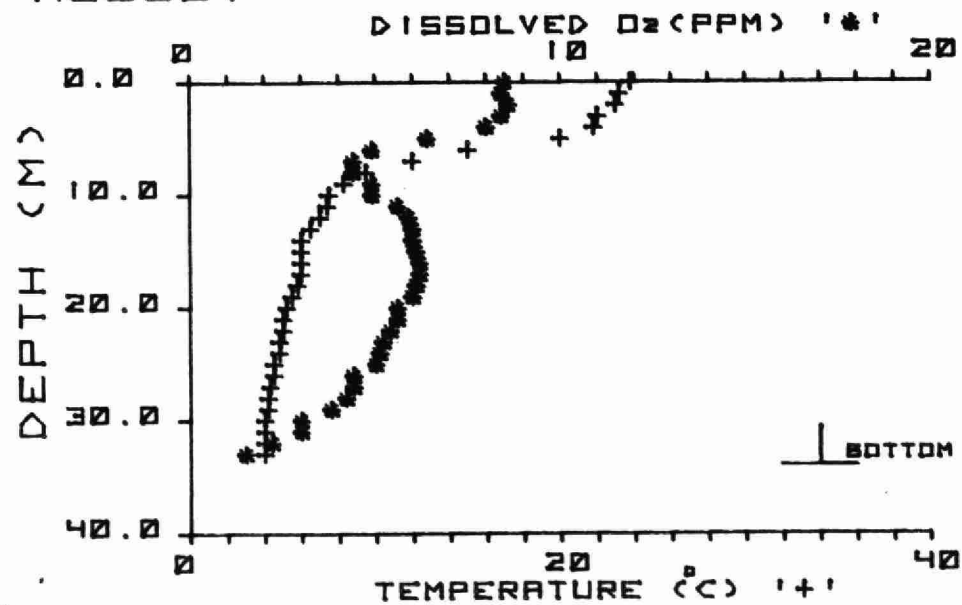
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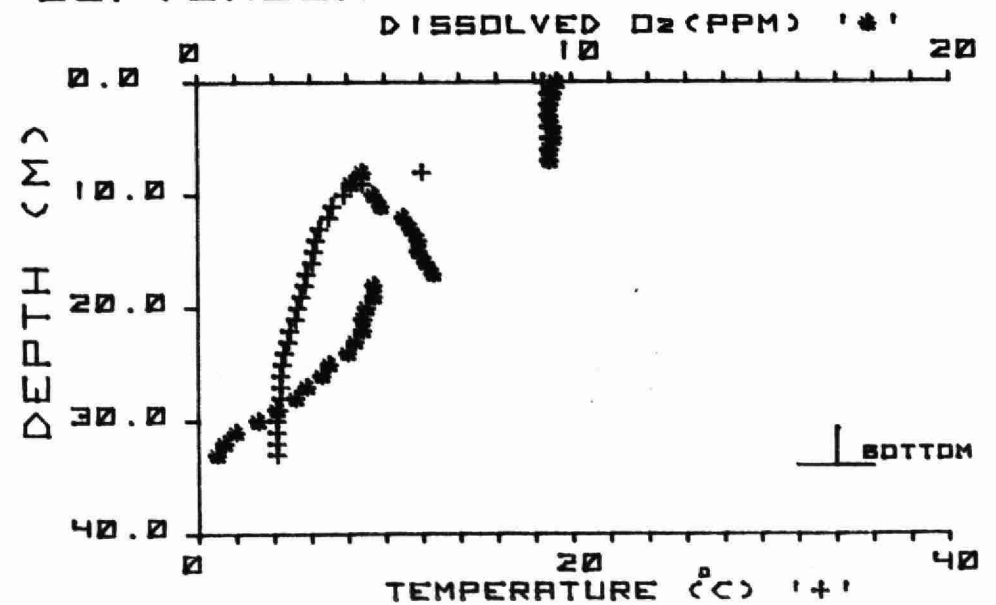
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AUGUST



SEPTEMBER

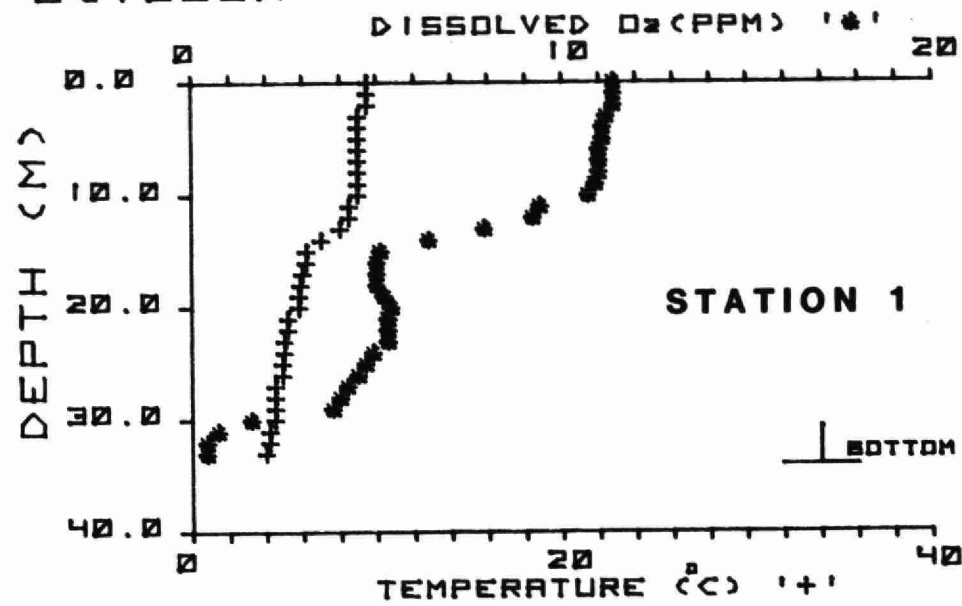


ESTEN LAKE

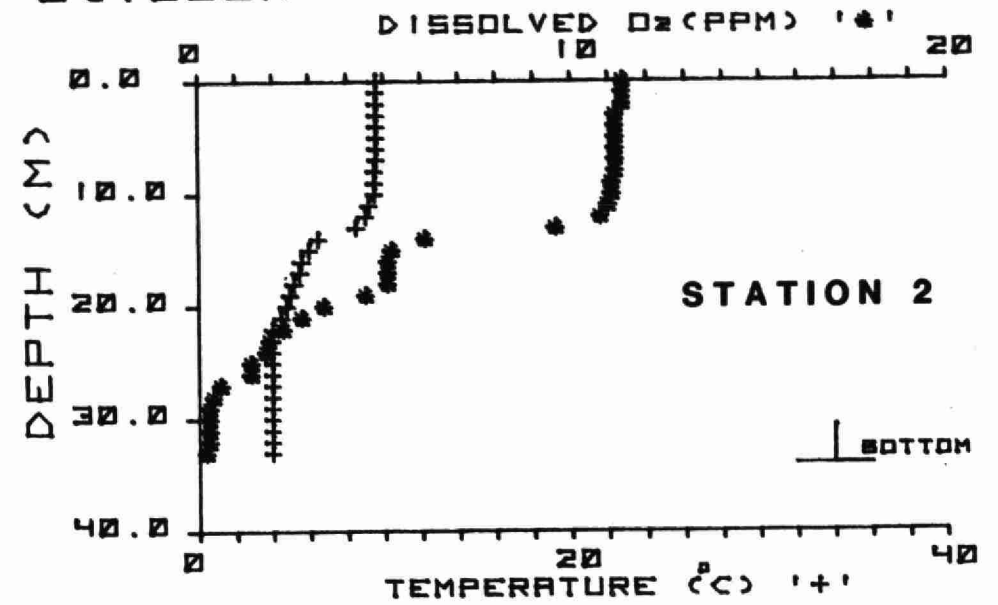
NORTHEASTERN REGION - M.O.E.

SUMMER 1981

OCTOBER



OCTOBER

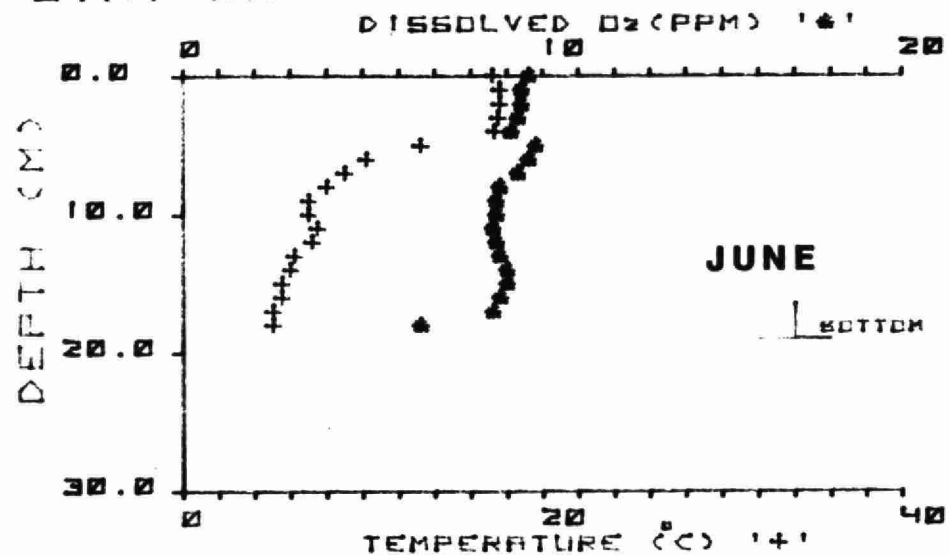


DEPOT LAKE

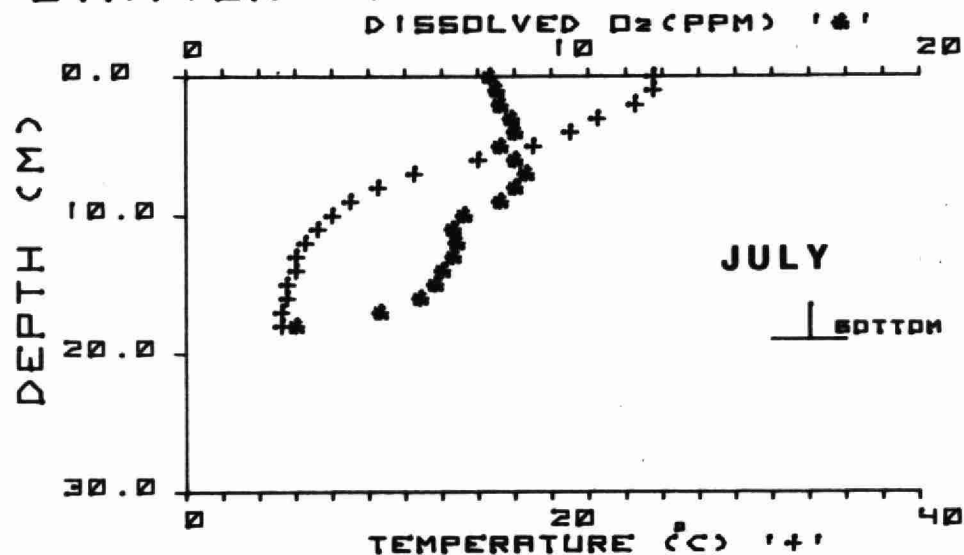
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SUMMER 1981

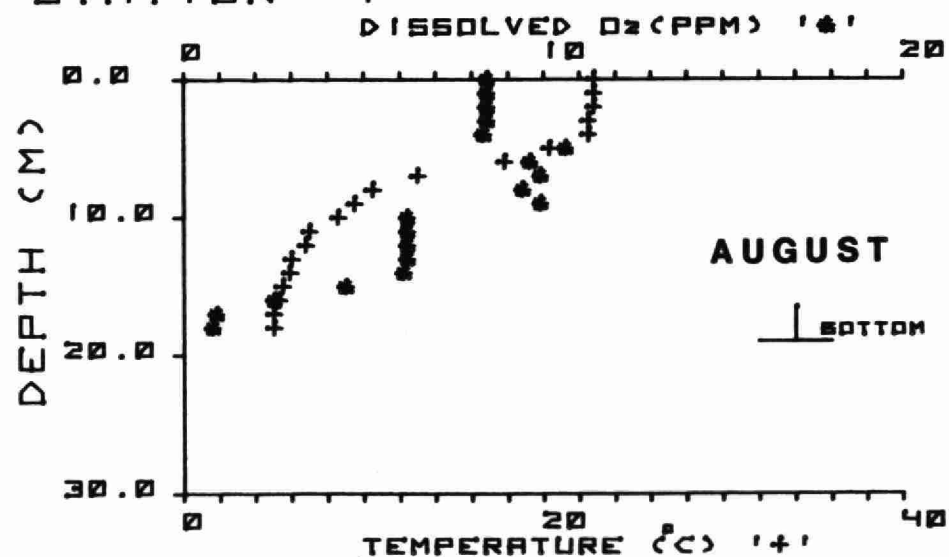
STATION 1



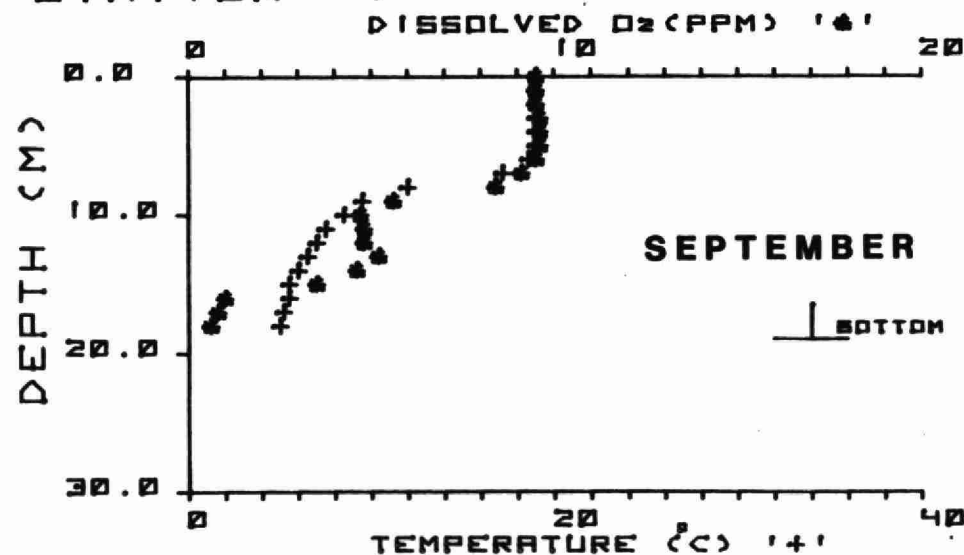
STATION 1



STATION 1



STATION 1

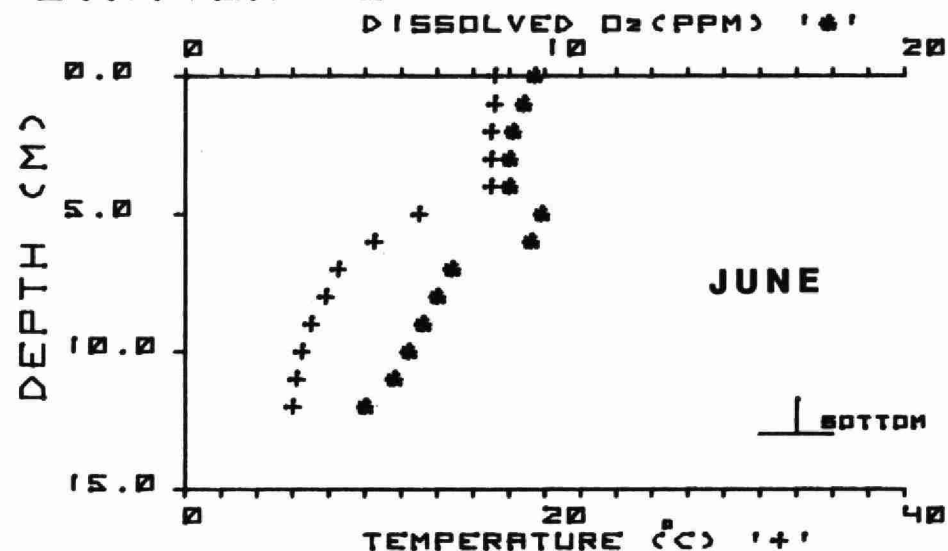


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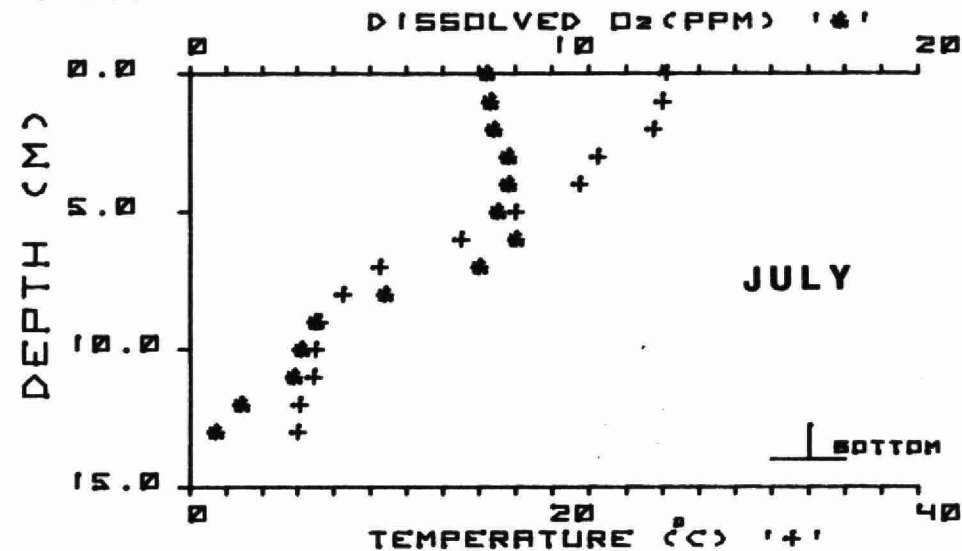
NORTHEASTERN REGION - M.O.E.

SUMMER 1981

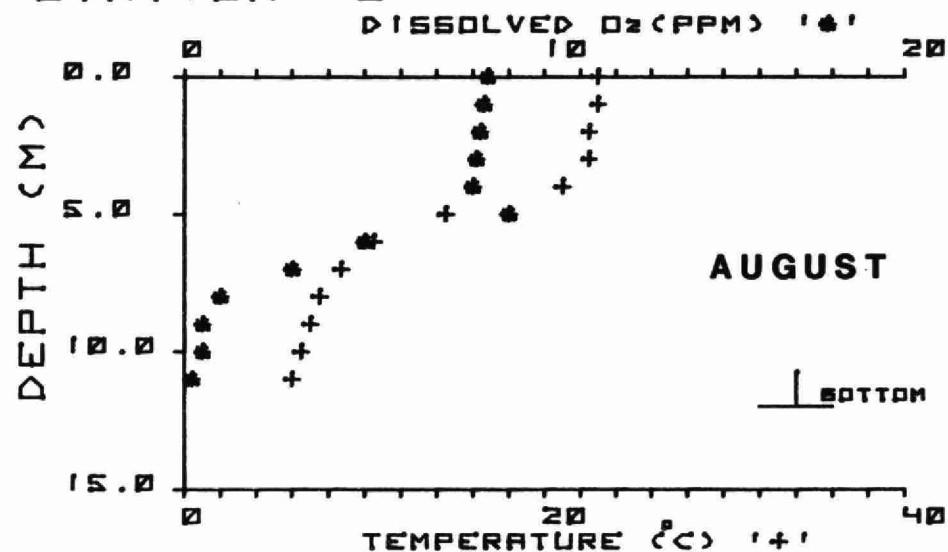
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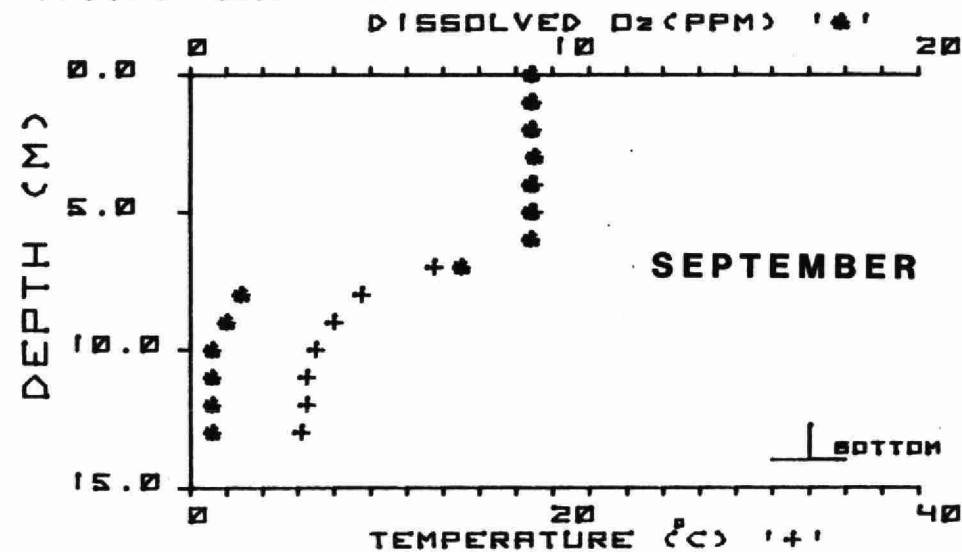
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STATION 2



STATION 2

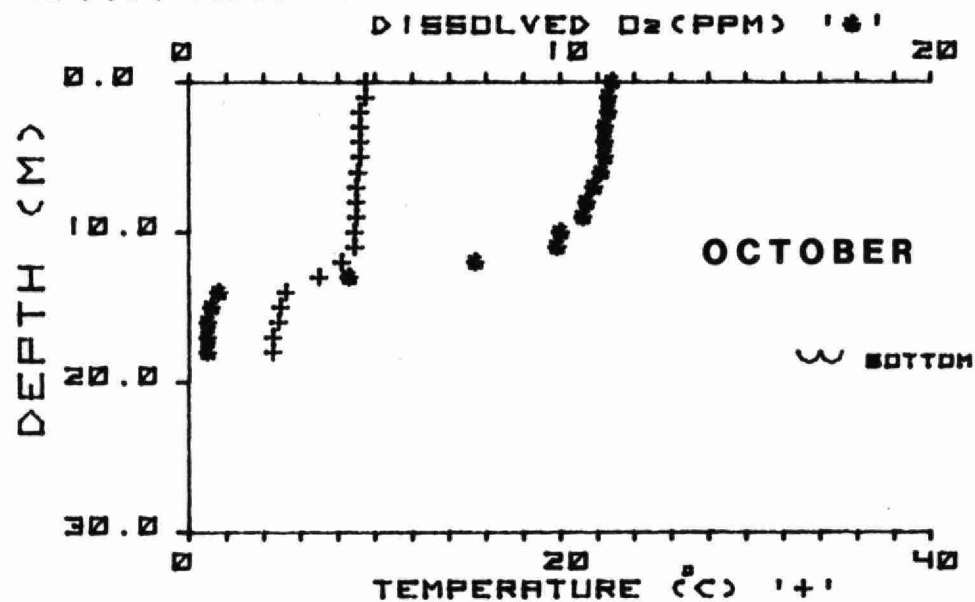


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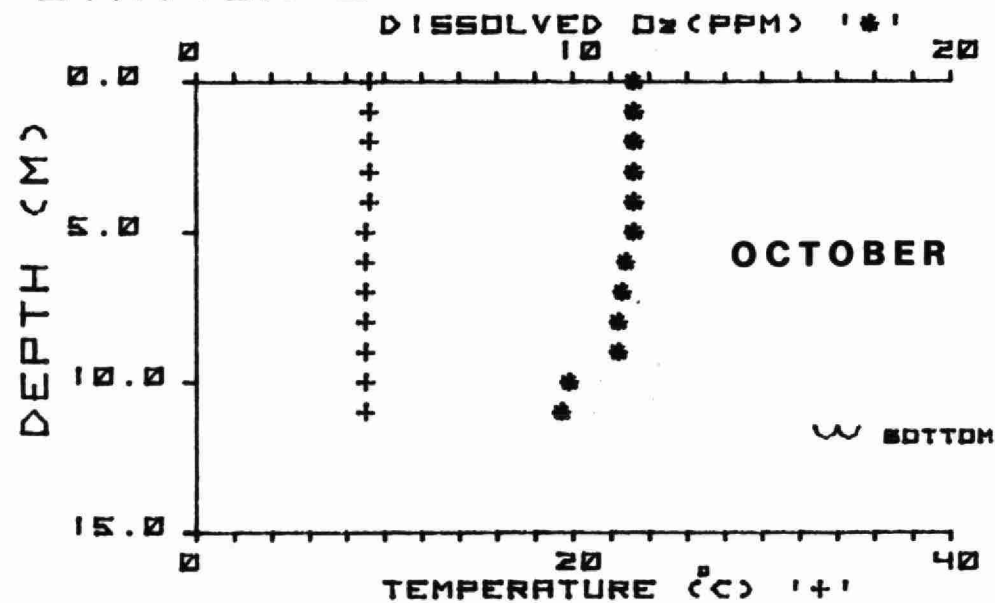
NORTHEASTERN REGION - M.O.E.

SUMMER 1981.

STATION 1



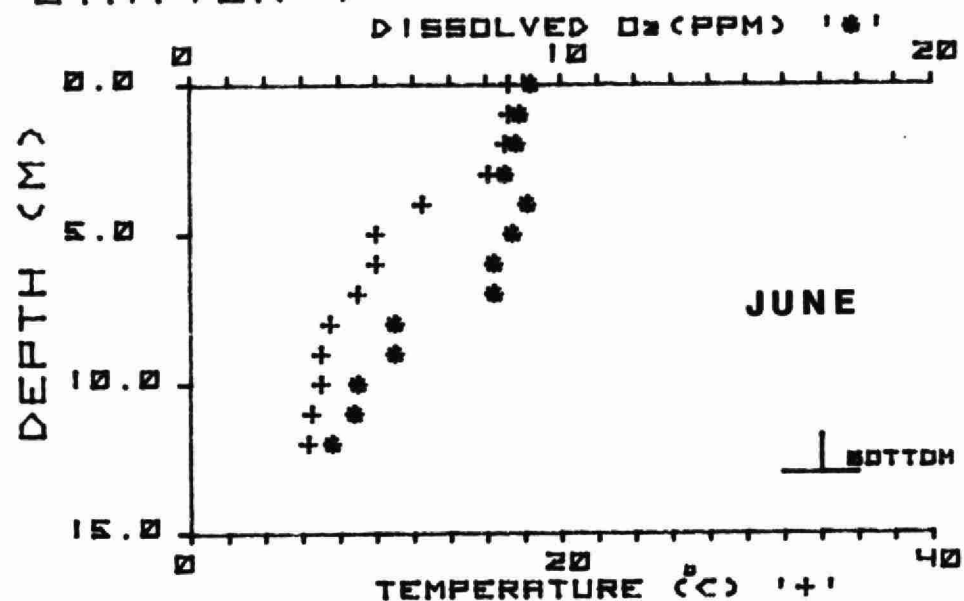
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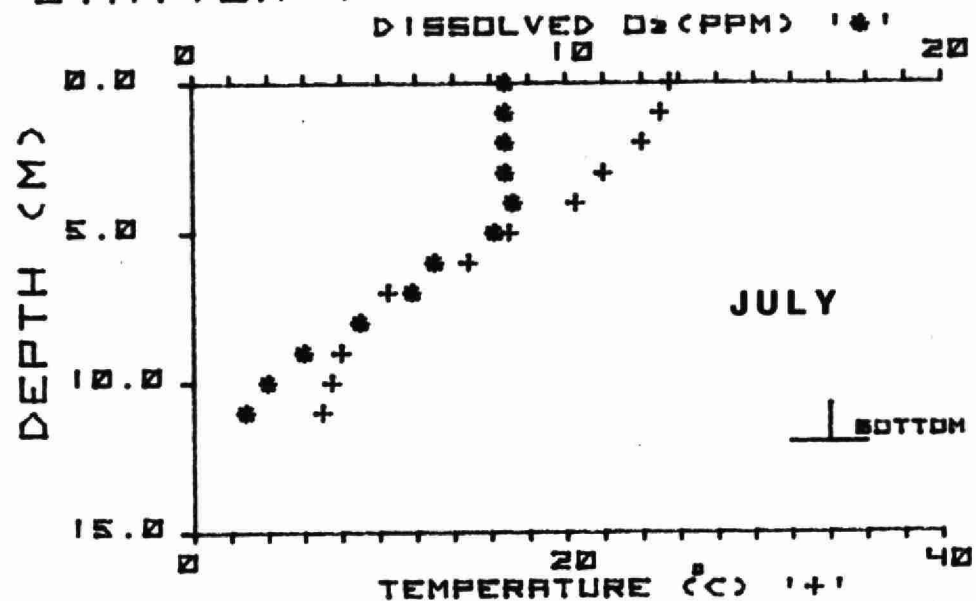
MCCARTHY LAKE

NORTHEASTERN REGION - M.O.E. SUMMER 1981

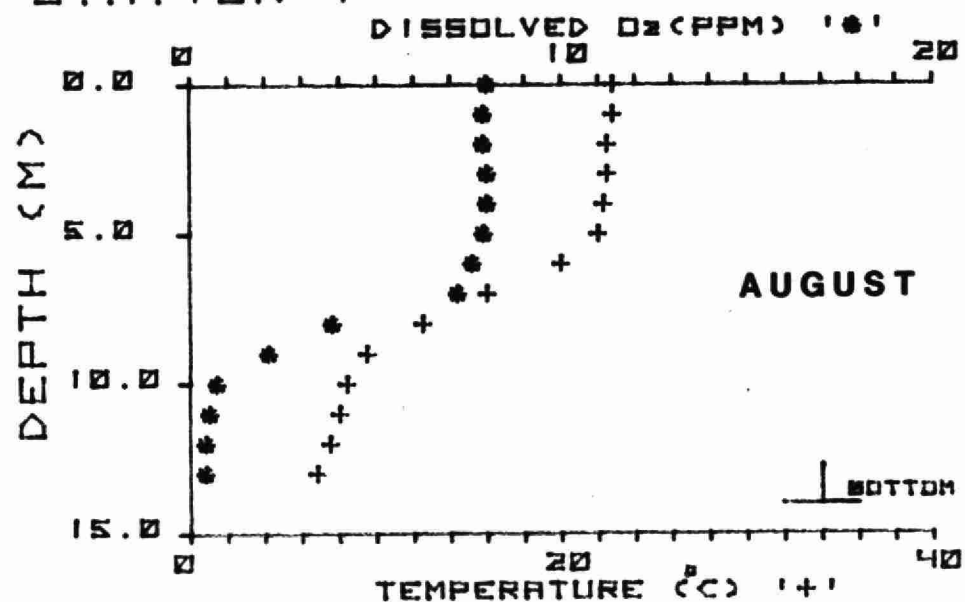
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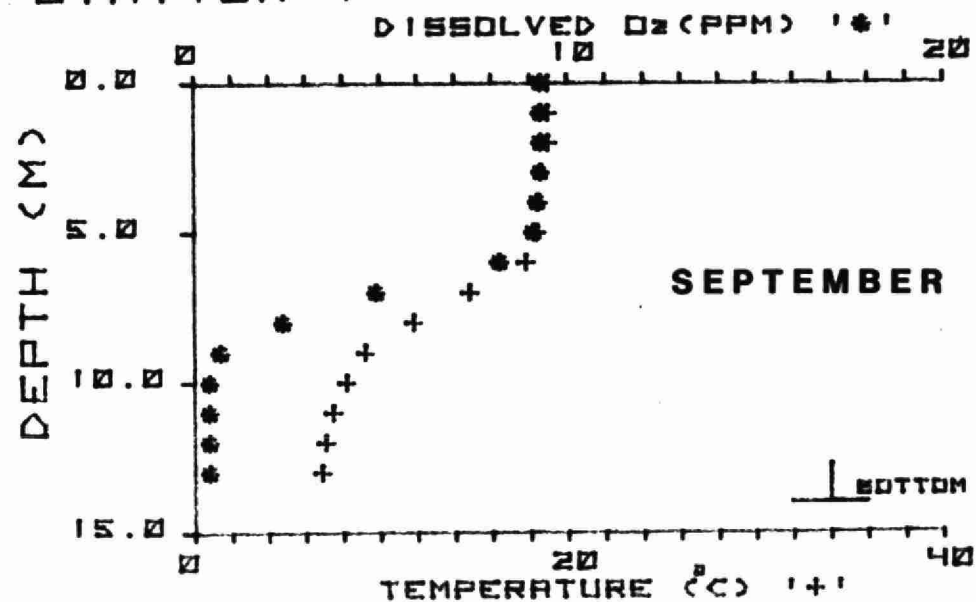
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STATION 1



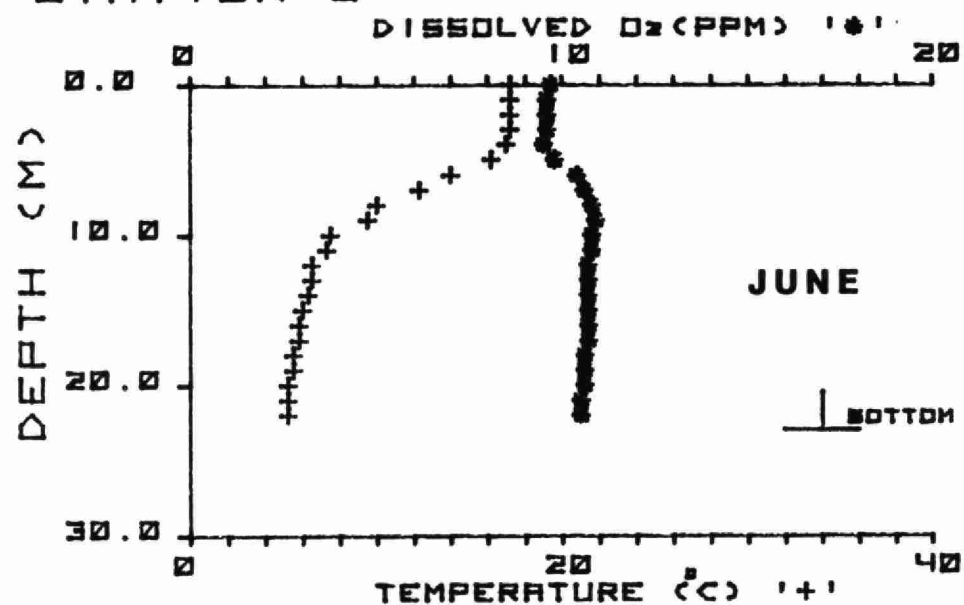
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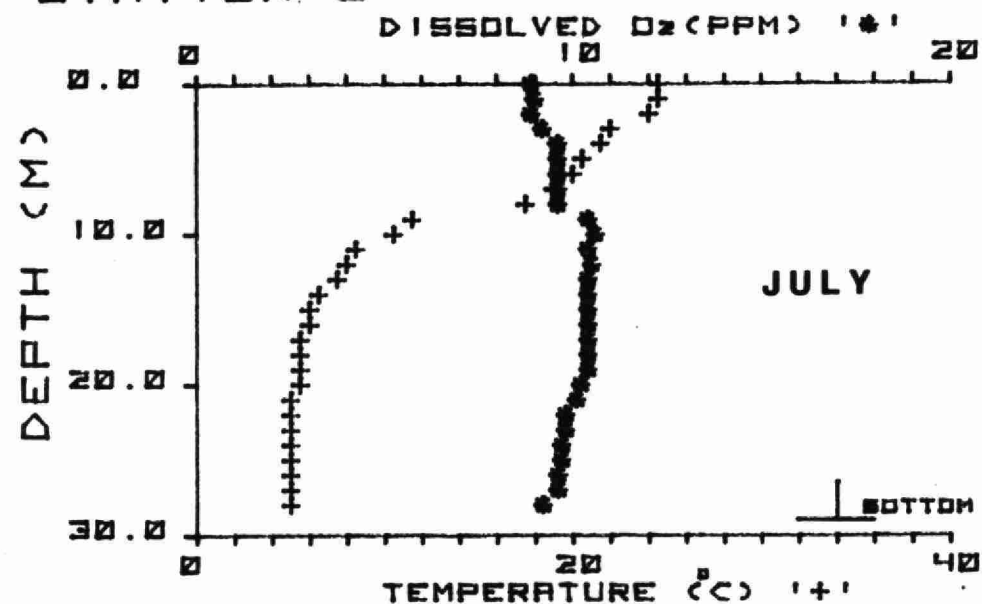
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NORTHEASTERN REGION - M.O.E. SUMMER 1981

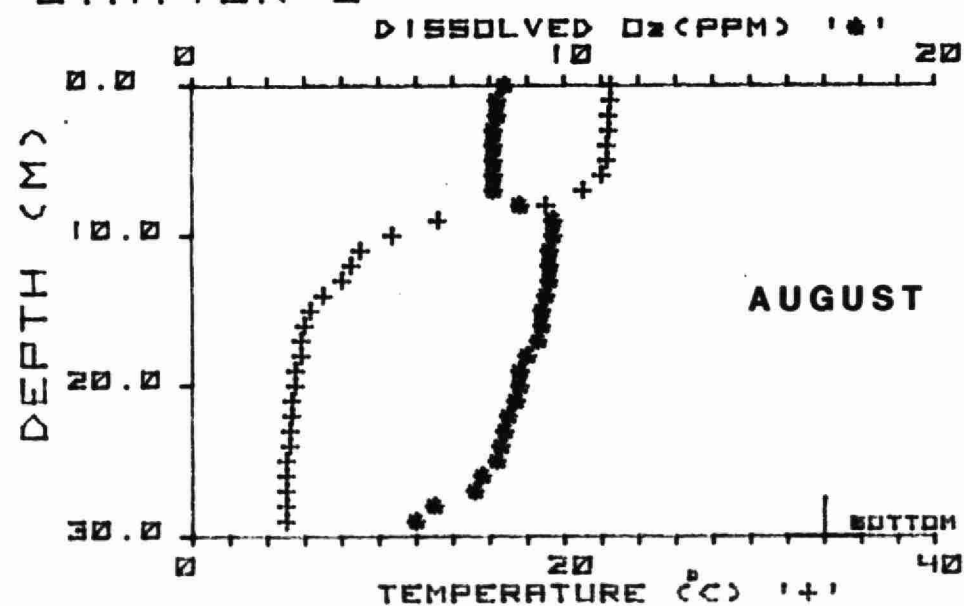
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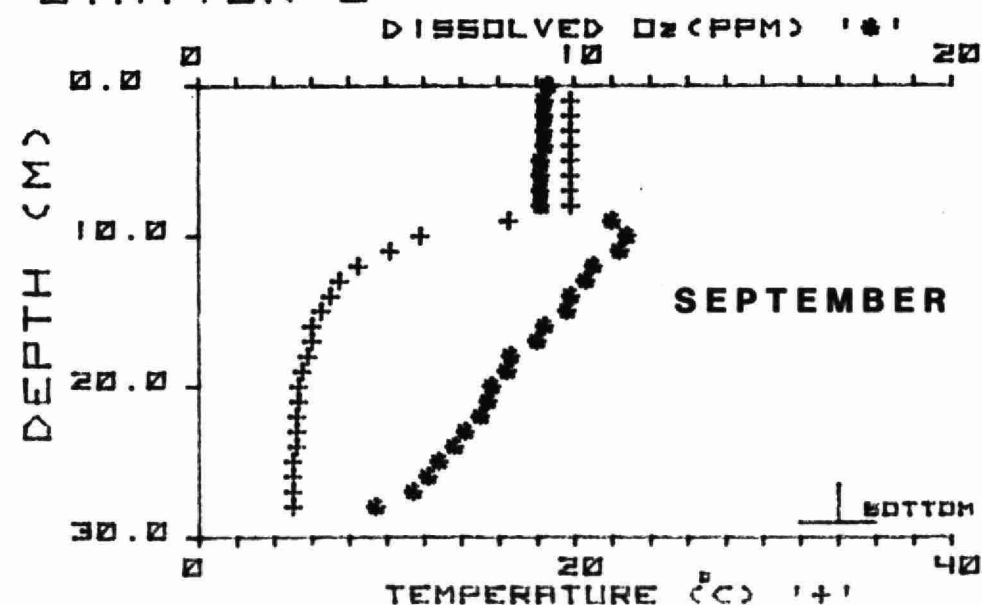
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STATION 2



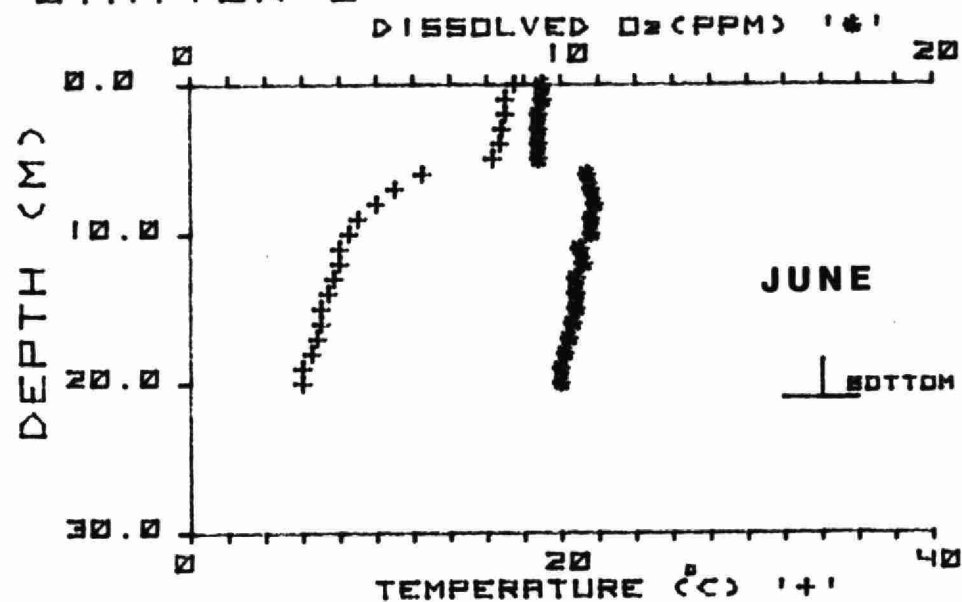
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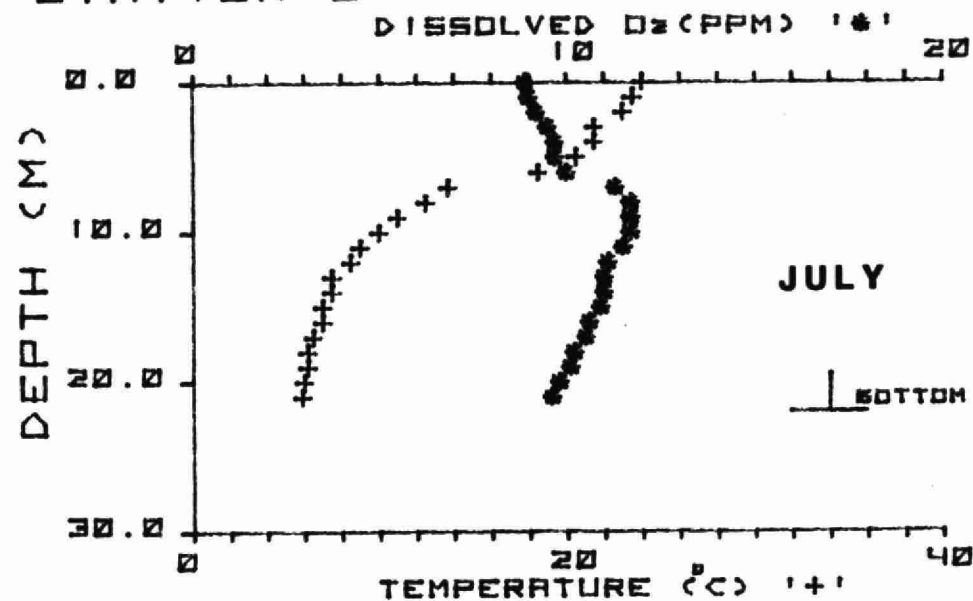
MCCARTHY LAKE

NORTHEASTERN REGION - M.O.E. SUMMER 1981

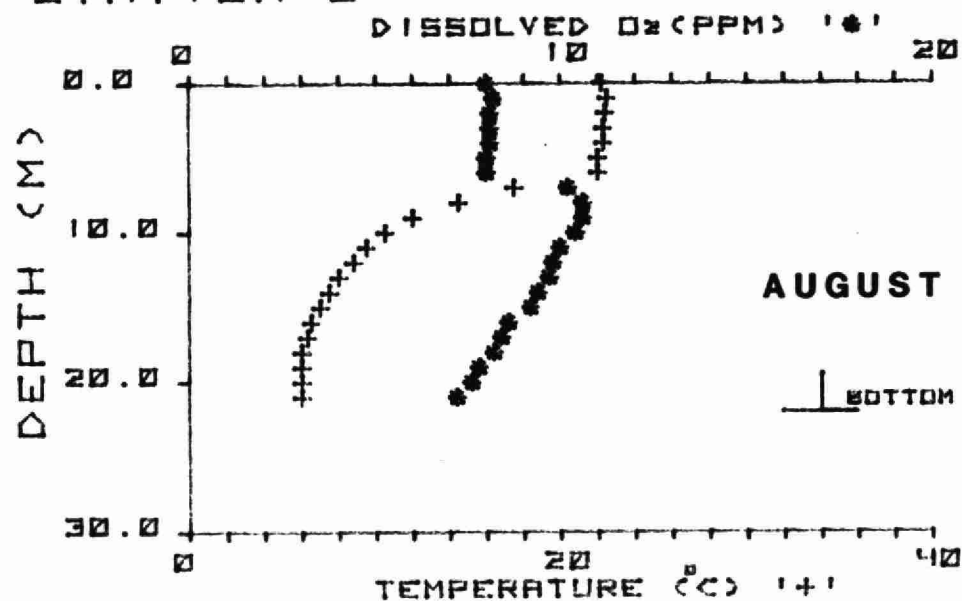
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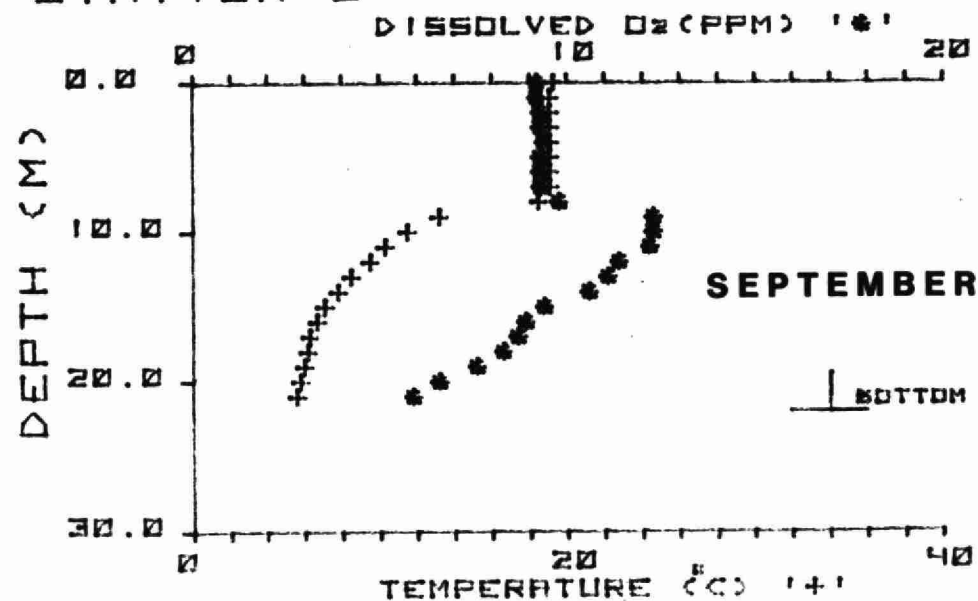
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STATION 3



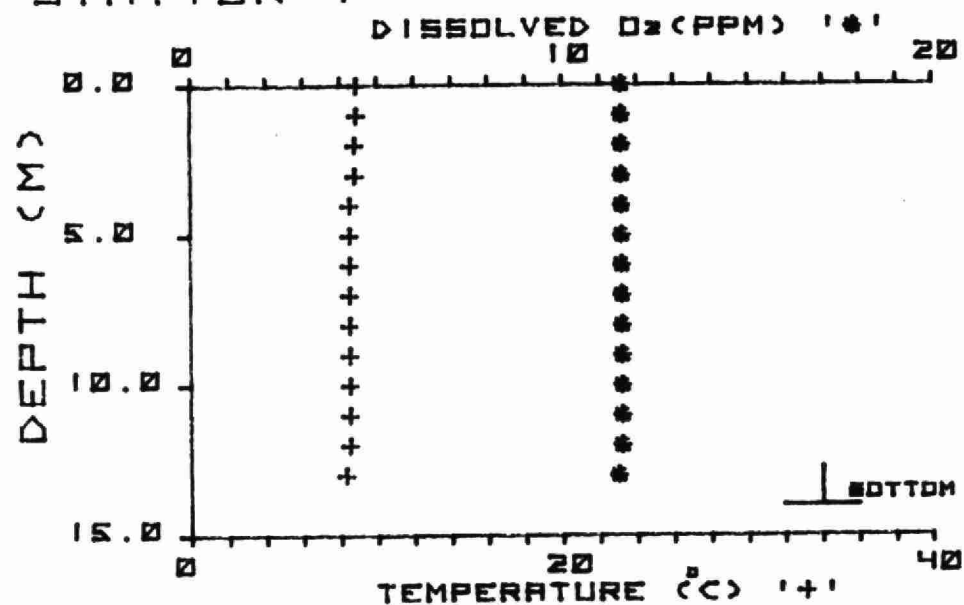
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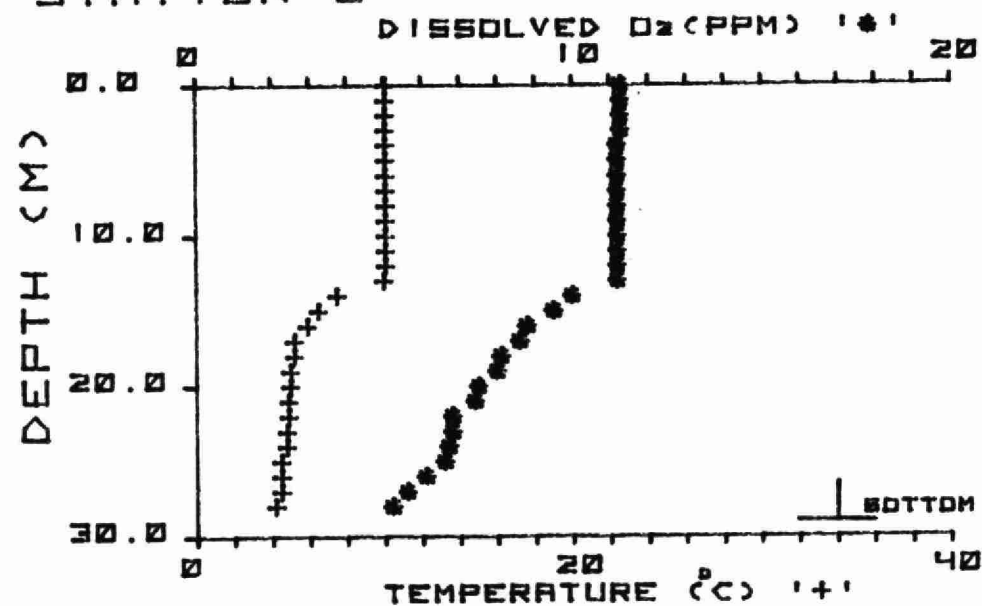
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NORTHEASTERN REGION - M.O.E. SUMMER 1981.

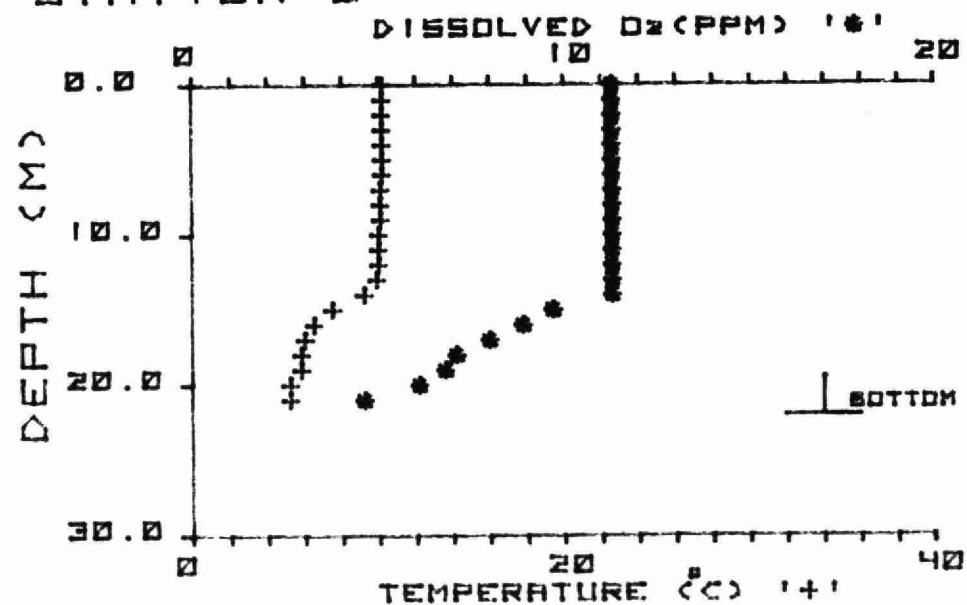
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STATION 2



STATION 3

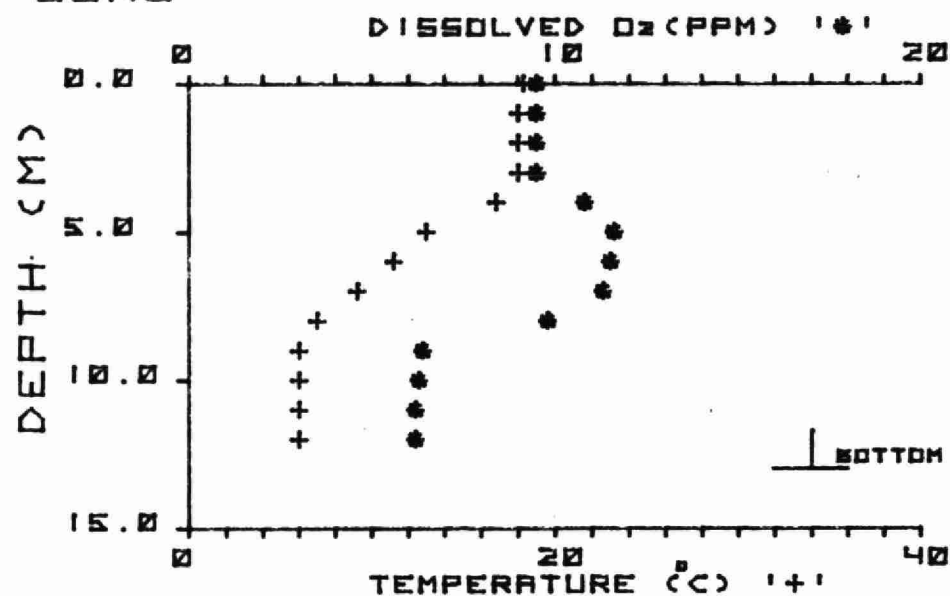


OCTOBER PROFILES

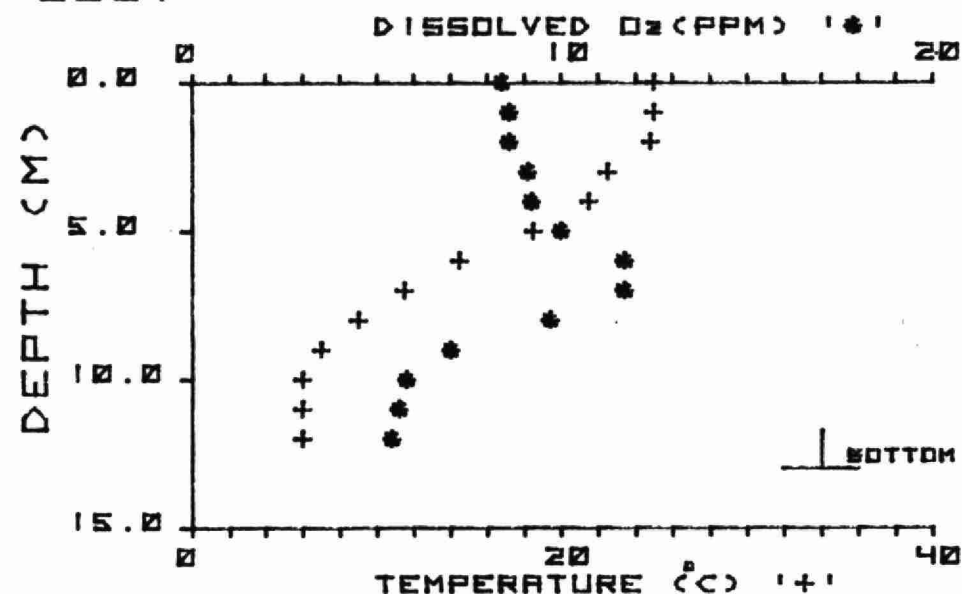
UNNAMED LAKE STN. 1

NORTHEASTERN REGION - M.O.E. SUMMER 1981

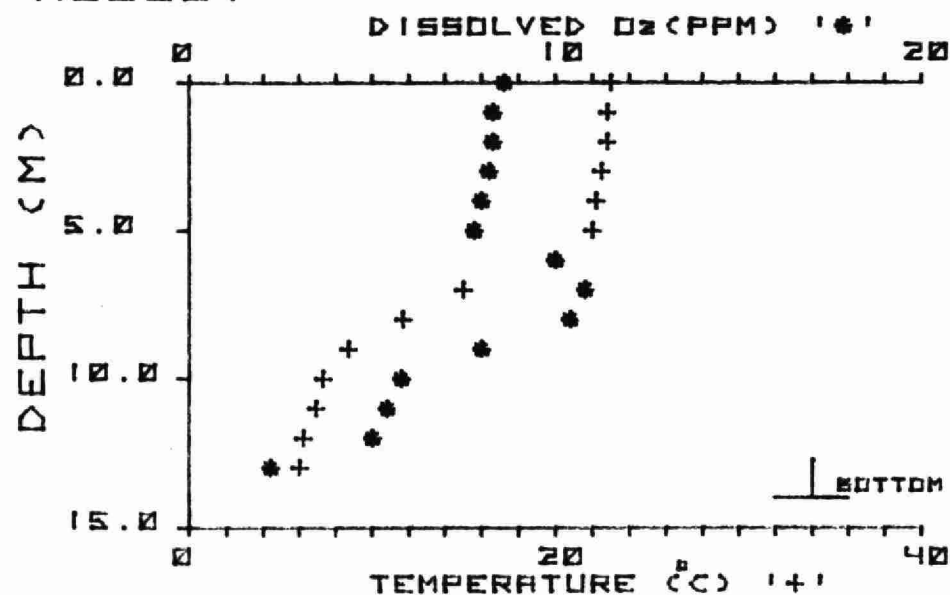
JUNE



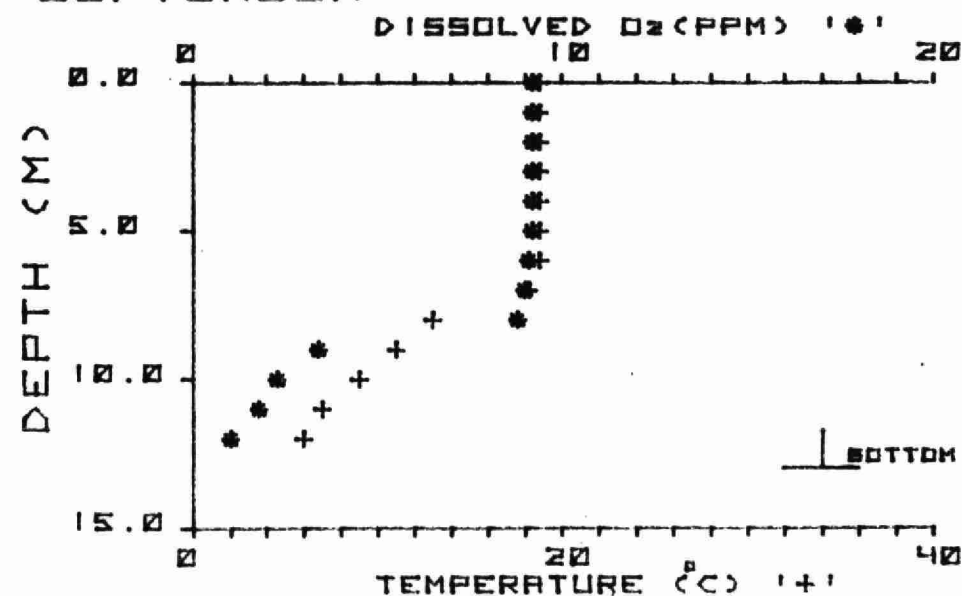
JULY



AUGUST



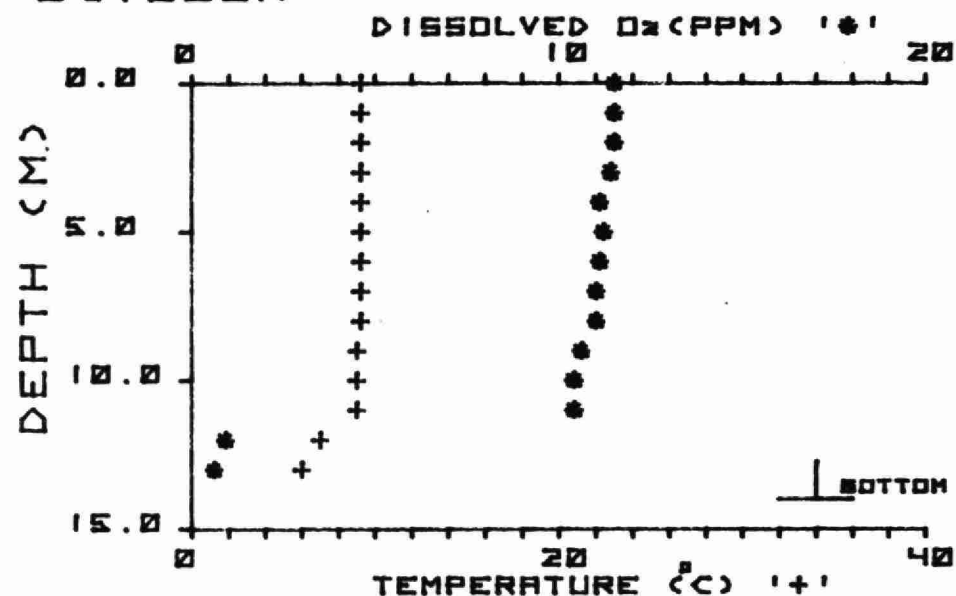
SEPTEMBER



UNNAMED LAKE
NORTHEASTERN REGION - M.O.E.

STN. 1
SUMMER 1981

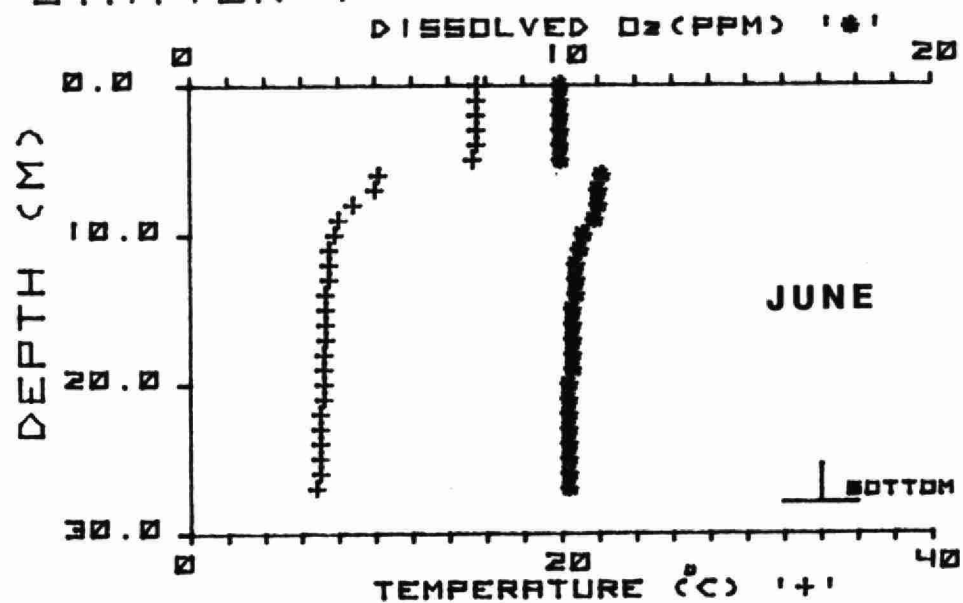
OCTOBER



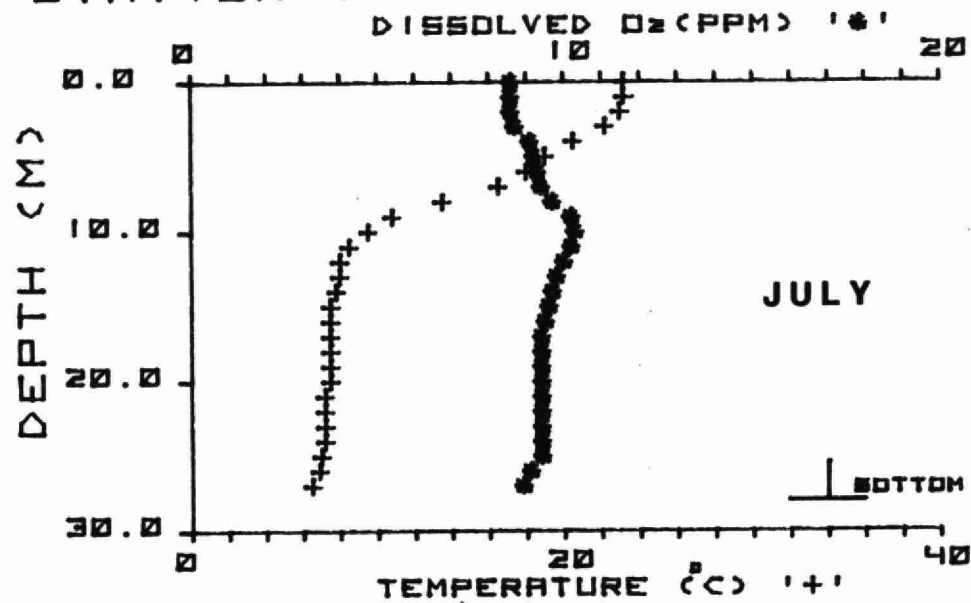
ELLIOT LAKE

NORTHEASTERN REGION - M.O.E. SUMMER 1981

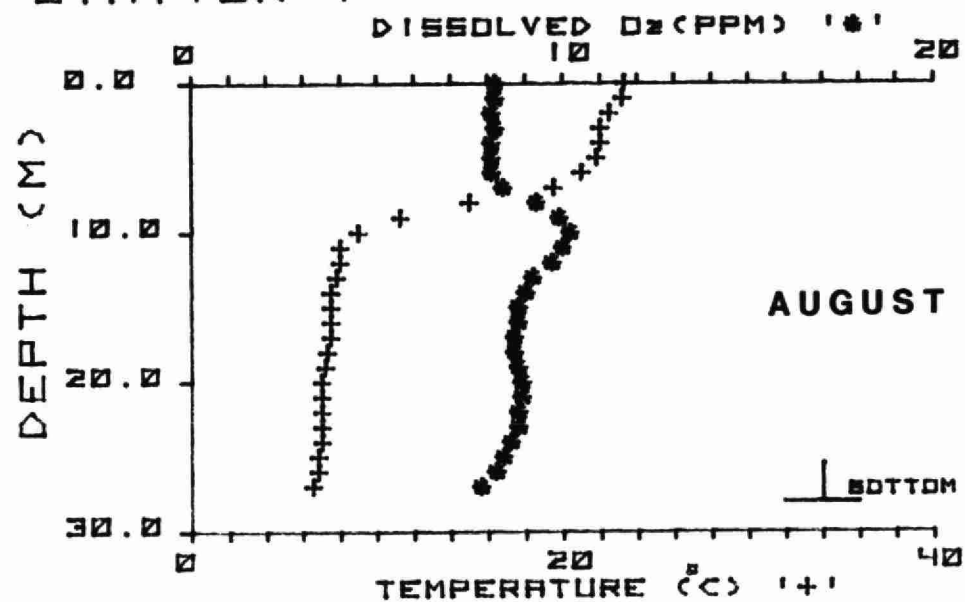
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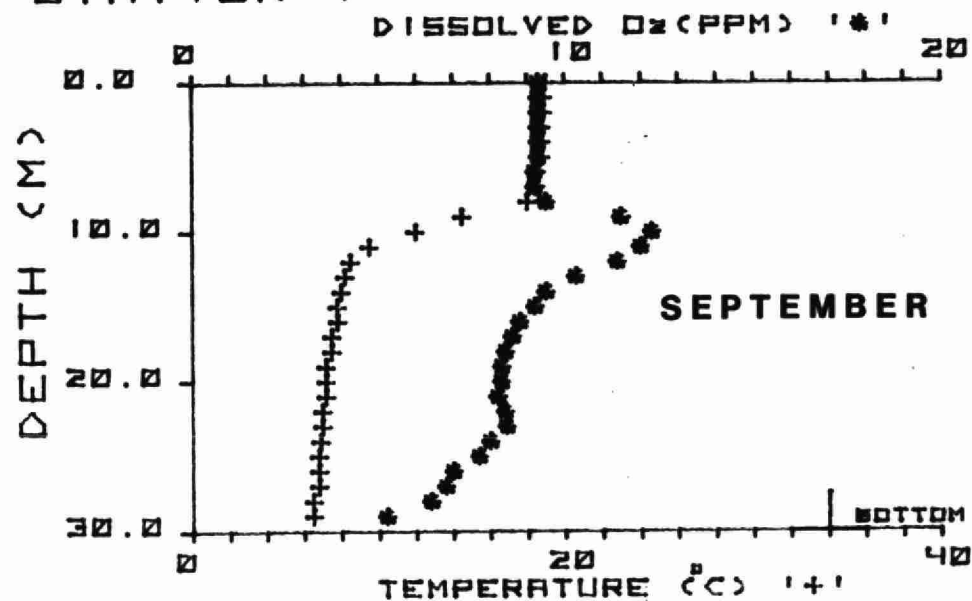
STATION 1



STATION 1

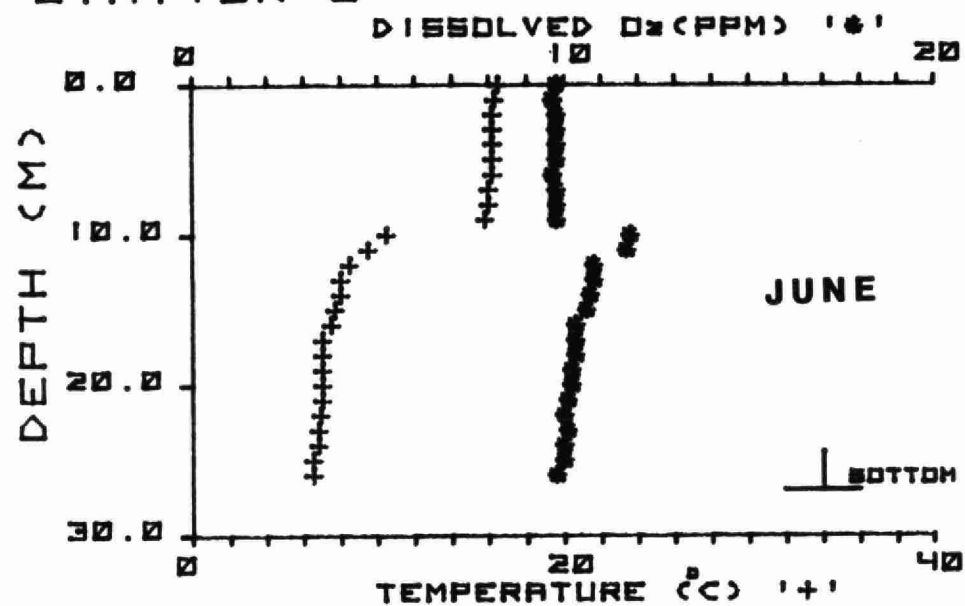


STATION 1

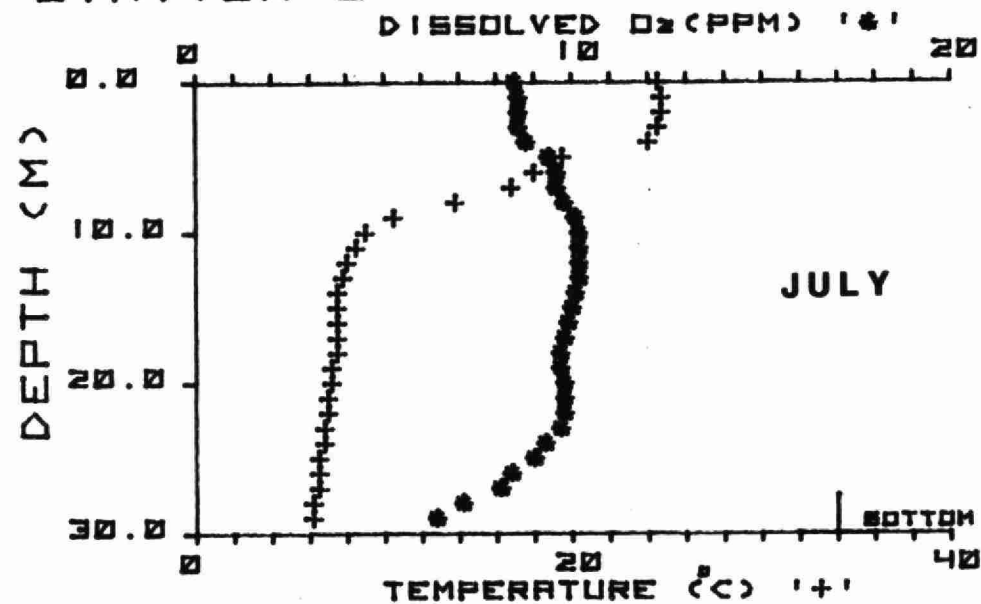


ELLIOT LAKE
NORTHEASTERN REGION - M.O.E. SUMMER 1981.

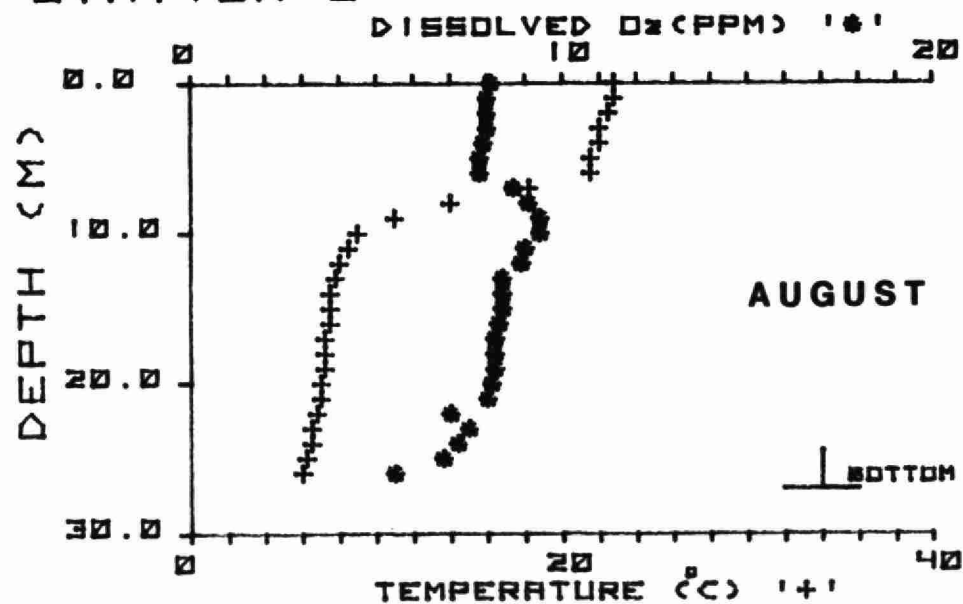
STATION 2



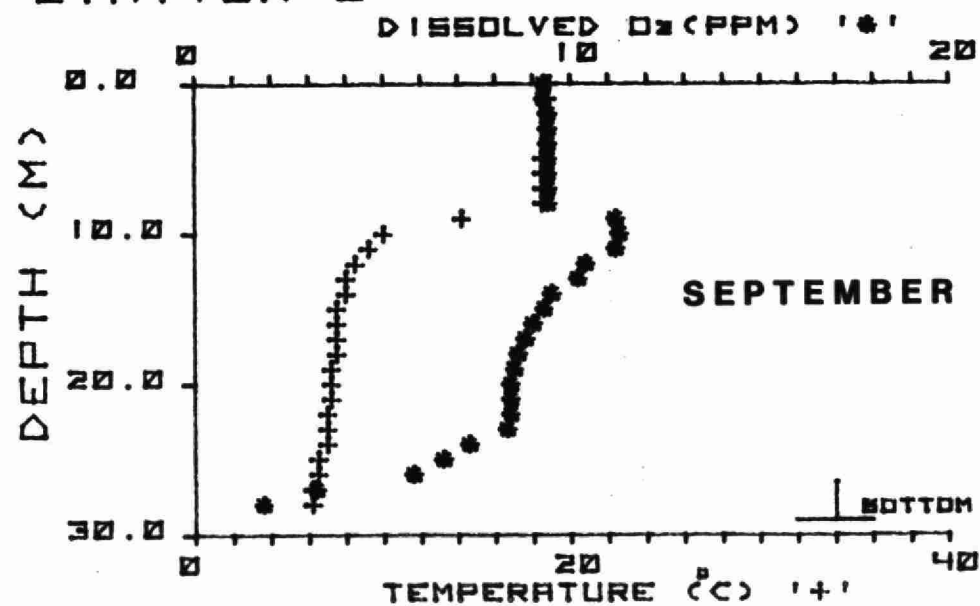
STATION 2



STATION 2



STATION 2

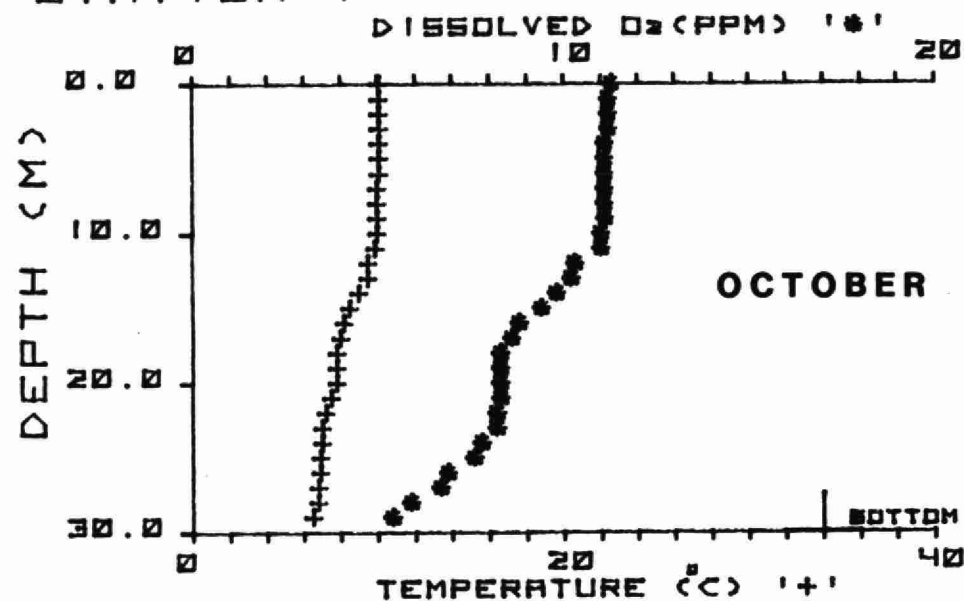


ELLIOT LAKE

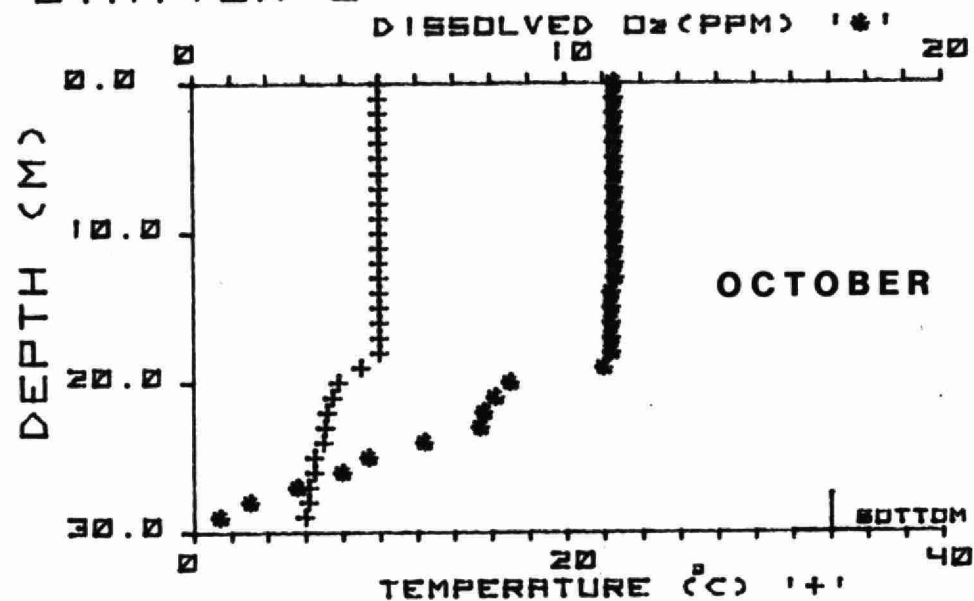
NORTHEASTERN REGION - M.O.E.

SUMMER 1981

STATION 1



STATION 2



APPENDIX III

PRESENCE OF PLANKTONIC ALGAE BY GENUS

PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

MONTHLY CUMULATIVE PERCENTAGE COMPOSITION OF PLANKTONIC
ALGAE BY CLASS

ICE FREE MEAN MONTHLY ESTIMATES OF ZOOPLANKTON
NUMBERS AND BIOMASS

BENTHOS DATA, 1981

PRESENCE OF PLANKTONIC ALGAE BY GENUS
1981

	Nordic Lake		Esten Lake		Depot Lake		McCarthy Lake			Elliot Lake		Unnamed
	Stn.1	Stn.2	Stn.1	Stn.2	Stn.1	Stn.2	Stn.1	Stn.2	Stn.3	Stn.1	Stn.2	Stn.1
BACILLARIOPHYCEAE												
Achnanthes								P	P			
Asterionella	P		P	P	P	P	P	P	P	P	P	
Cyclotella	P	P	P	P	P	P	P	P	P	P	P	P
Cymbella			P	P								
Diatoma				P	P	P						
Epithemia							P					
Eunotia												P
Fragilaria	P	P	P	P	P	P	P		P			P
Melosira	P		P		P	P	P		P	P	P	P
Navicula		P	P	P		P	P		P	P		
Nitzschia	P	P	P	P		P	P	P	P			
Pinnularia									P			
Rhizosolenia									P	P	P	
Stephanodiscus			P			P						
Surirella							P		P			
Synedra	P	P	P	P	P	P	P	P	P	P	P	P
Tabellaria	P	P	P	P	P	P	P	P	P	P	P	P
Unidentified Bacillario- phycean												P
CHLOROPHYCEAE												
Ankistrodesmus							P					
Arthrodesmus		P	P	P		P	P	P	P	P	P	

	Nordic Lake		Esten Lake		Depot Lake		McCarthy Lake			Elliot Lake		Unnamed
	Stn.1	Stn.2	Stn.1	Stn.2	Stn.1	Stn.2	Stn.1	Stn.2	Stn.3	Stn.1	Stn.2	Stn.1
Botryococcus						P	P	P		P	P	P
Cerasterias	P											
Chlamydomonas	P	P	P	P	P	P	P	P	P	P	P	P
Closterium	P	P	P	P	P	P	P	P	P	P	P	P
Coelastrum			P			P						
Cosmarium		P	P	P			P	P	P	P	P	
Crucigenia								P	P			P
Dictyosphaerium			P	P								P
Eudorina			P	P								
Gemellicystis	P	P							P			
Gloeocystis	P	P	P	P	P	P	P	P	P	P	P	P
Golenkinia			P									
Gonium			P	P	P	P						
Gyromitus			P	P	P	P	P	P				
Micractinium	P	P	P	P		P						
Monoraphidium	P	P	P	P	P	P	P	P	P	P	P	P
Mougeotia		P							P			
Nephrocytium		P			P					P	P	
Oedogonium	P	P										
Oocystis	P	P	P	P	P	P	P	P	P	P	P	P
Pandorina					P							
Paramastix	P	P		P								
Paulschulzia								P				
Pediastrum		P					P	P	P			

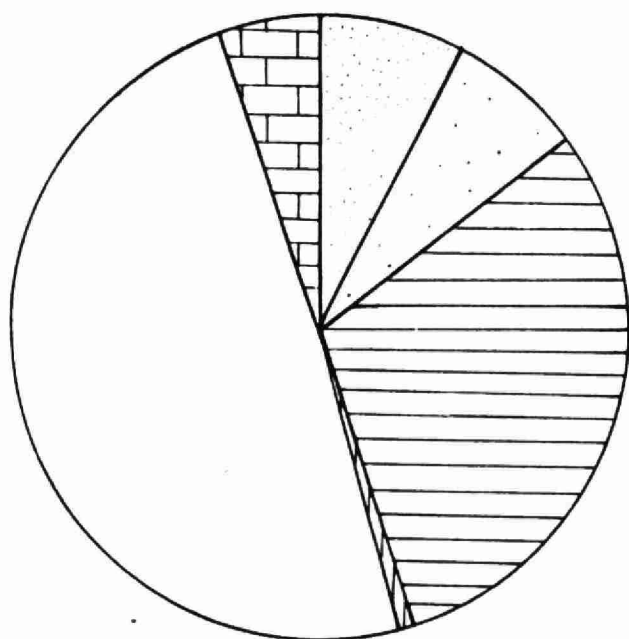
[illegible]

	Nordic Lake		Esten Lake		Depot Lake		McCarthy Lake			Elliot Lake		Unnamed
	Stn.1	Stn.2	Stn.1	Stn.2	Stn.1	Stn.2	Stn.1	Stn.2	Stn.3	Stn.1	Stn.2	Stn.1
Epipyxis					P	P						
Isthmochloran									P			
Kephyrion	P	P			P	P	P	P	P	P	P	P
Mallomonas	P		P	P	P	P	P	P	P	P	P	
Ochromonas	P		P	P	P	P	P					
Pseudokephyrion	P	P					P					
Rhizochrysis						P						
Salpingoeca			P	P	P	P	P					
Spiniferomonas	P	P				P	P		P	P	P	
Synura	P	P	P		P	P	P	P	P	P	P	P
Uroglena	P	P	P	P	P	P	P	P	P	P	P	
Unidentified Chrysomonads	P	P	P	P	P	P	P	P	P	P	P	P
Unidentified Chrysophycean							P	P				
CRYPTOPHYCEAE												
Cryptaulax	P	P	P	P	P	P	P	P	P	P	P	
Cryptomonas	P	P	P	P	P	P	P	P	P	P	P	P
Katablepharis	P	P	P	P	P	P	P	P	P	P	P	P
Rhodomonas	P	P	P	P	P	P	P	P	P	P	P	P
CYANOPHYCEAE												
Anabaena			P	P	P	P	P			P	P	
Aphanothece	P		P		P	P	P	P	P	P	P	
Chroococcus	P	P	P		P		P	P		P	P	P
Gomphosphaeria	P	P	P	P	P	P			P			
Lyngbya				P				P	P			P

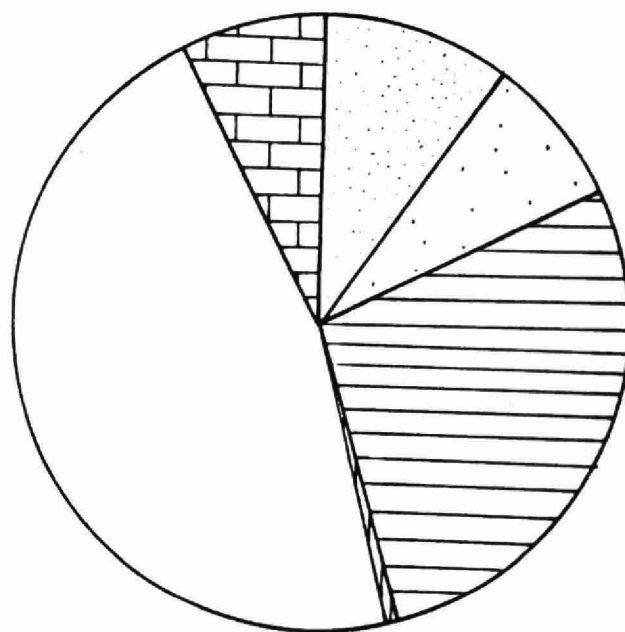
	Nordic Lake		Esten Lake		Depot Lake		McCarthy Lake			Elliot Lake		Unnamed
	Stn.1	Stn.2	Stn.1	Stn.2	Stn.1	Stn.2	Stn.1	Stn.2	Stn.3	Stn.1	Stn.2	Stn.1
Merismopedia	P	P	P	P			P	P	P	P	P	P
Microcystis			P	P								
Oscillatoria	P	P	P	P	P	P	P	P	P	P	P	
Phormidium			P	P								
Rhabdoderma							P			P		
Unidentified Cyanophycean						P	P					
DINOPHYCEAE												
Ceratium	P	P	P	P	P	P	P					
Gymnodinium	P	P	P	P	P	P	P	P	P			
Peridinium	P	P	P	P	P	P	P	P	P	P	P	P
EUGLENOPHYCEAE												
Euglena				P		P						

PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

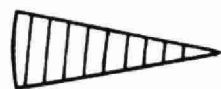
NORDIC LAKE 1981



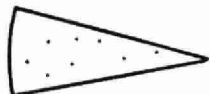
STATION 1



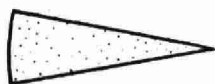
STATION 2



Cyanophyceae



Cryptophyceae



Dinophyceae



Chrysophyceae

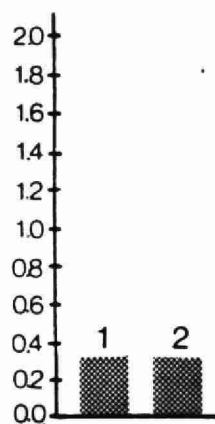


Bacillariophyceae



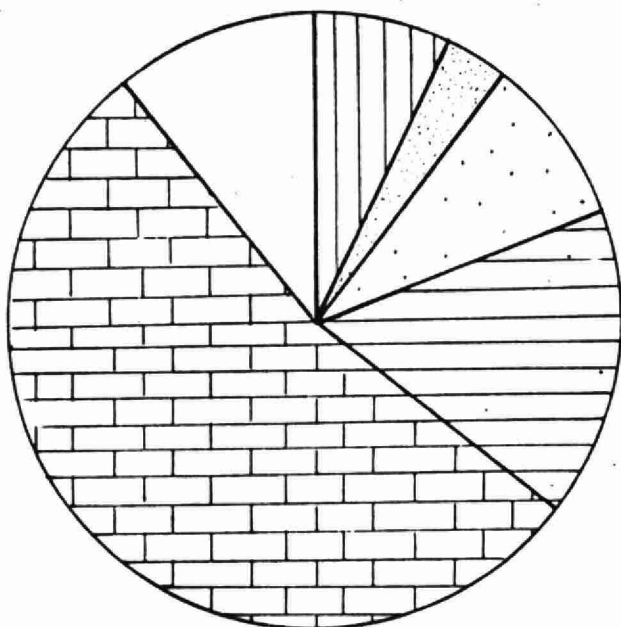
Chlorophyceae

Phytoplankton
Biomass mm^3/L

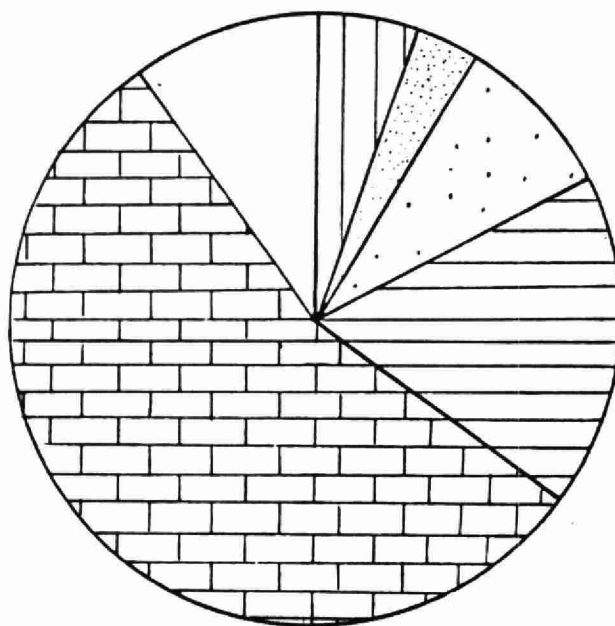


PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

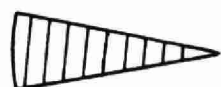
ESTEN LAKE 1981



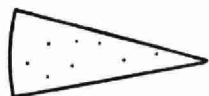
STATION 1



STATION 2



Cyanophyceae



Cryptophyceae



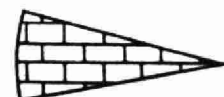
Dinophyceae



Chrysophyceae

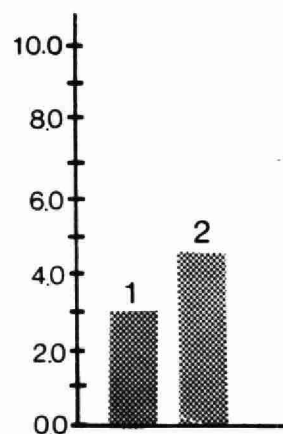


Bacillariophyceae



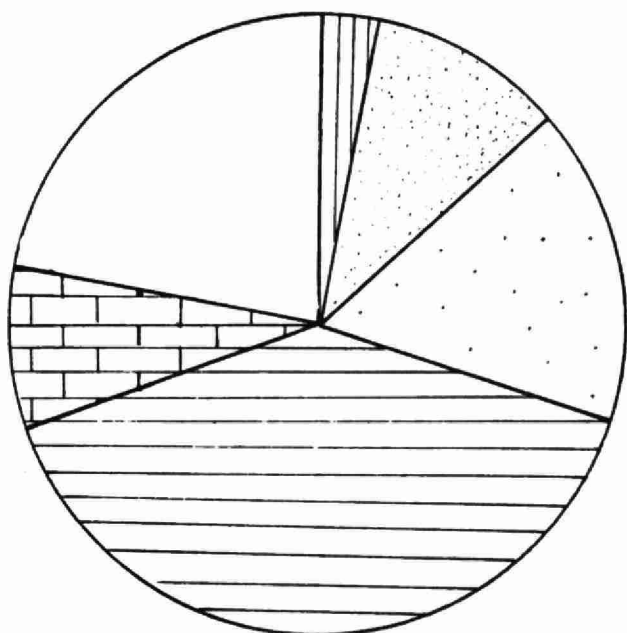
Chlorophyceae

Phytoplankton
Biomass mm^3/L

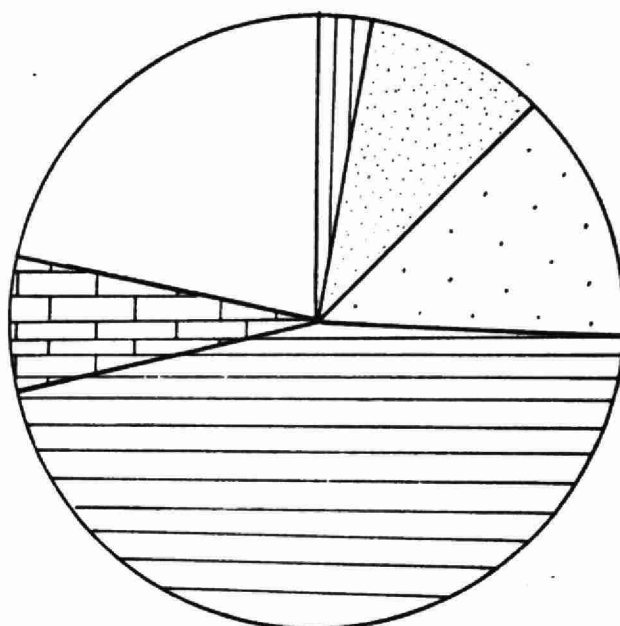


PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

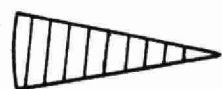
DEPOT LAKE 1981



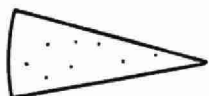
STATION 1



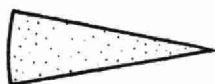
STATION 2



Cyanophyceae



Cryptophyceae



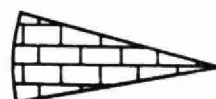
Dinophyceae



Chrysophyceae

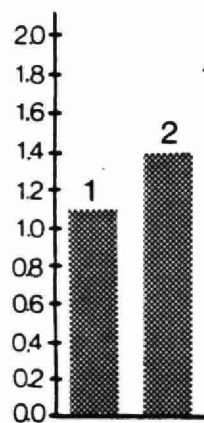


Bacillariophyceae



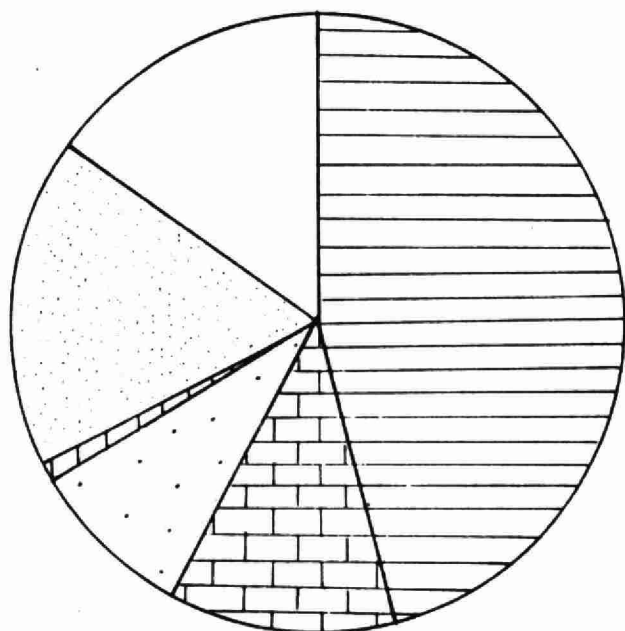
Chlorophyceae

Phytoplankton
Biomass mm^3/L

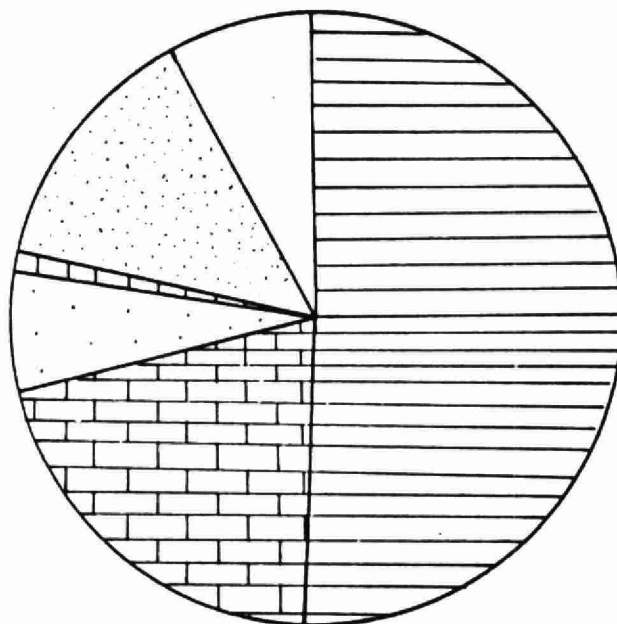


PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

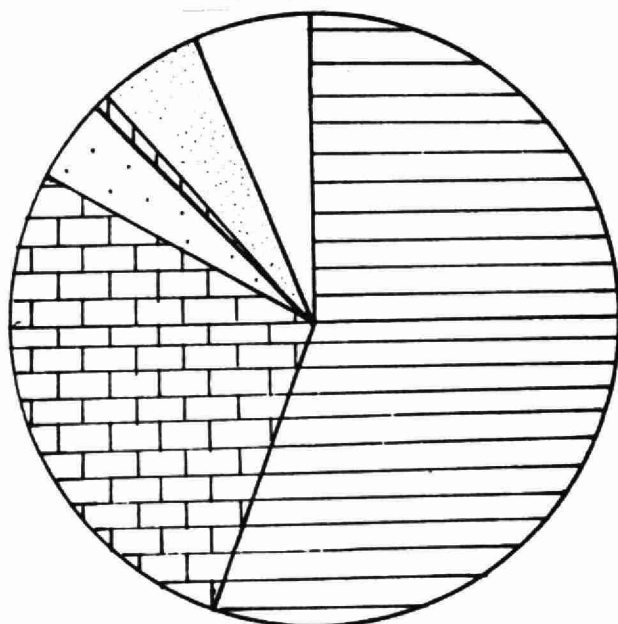
McCARTHY LAKE 1981



STATION 1

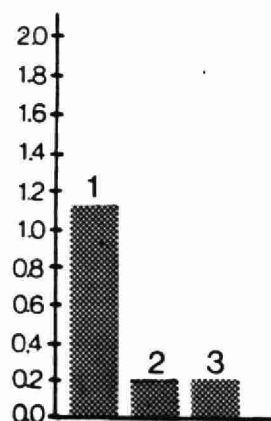


STATION 2

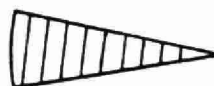


STATION 3

Phytoplankton
Biomass mm^3/L



Chrysophyceae



Cyanophyceae



Bacillariophyceae



Cryptophyceae



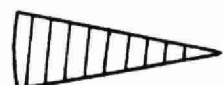
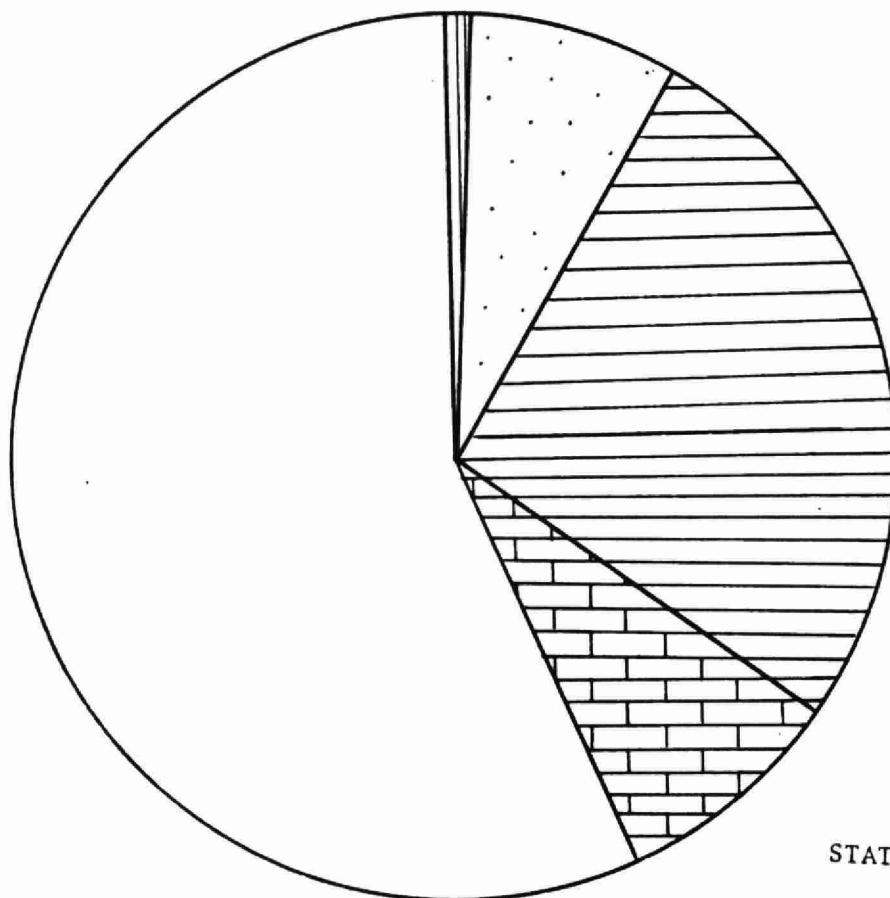
Chlorophyceae



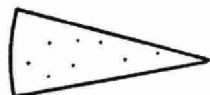
Dinophyceae

PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

UNNAMED LAKE 1981



Cyanophyceae



Cryptophyceae



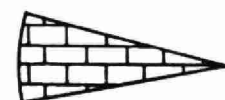
Dinophyceae



Chrysophyceae

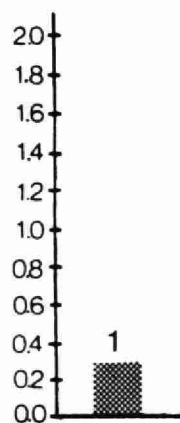


Bacillariophyceae



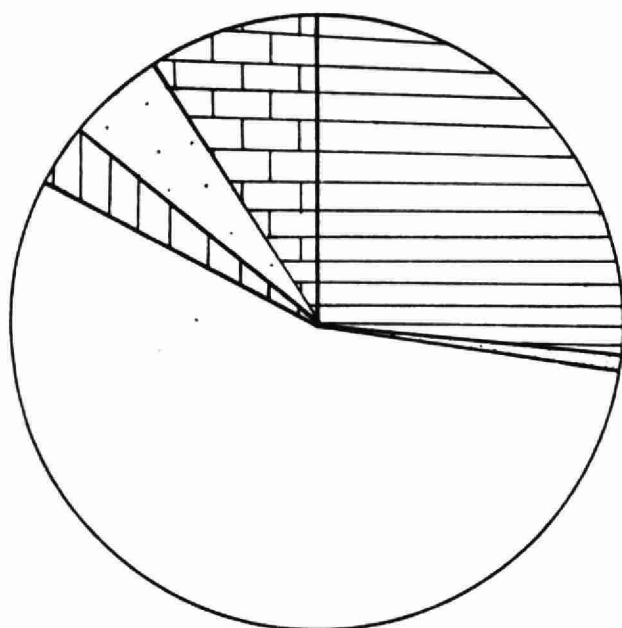
Chlorophyceae

Phytoplankton
Biomass mm^3/L

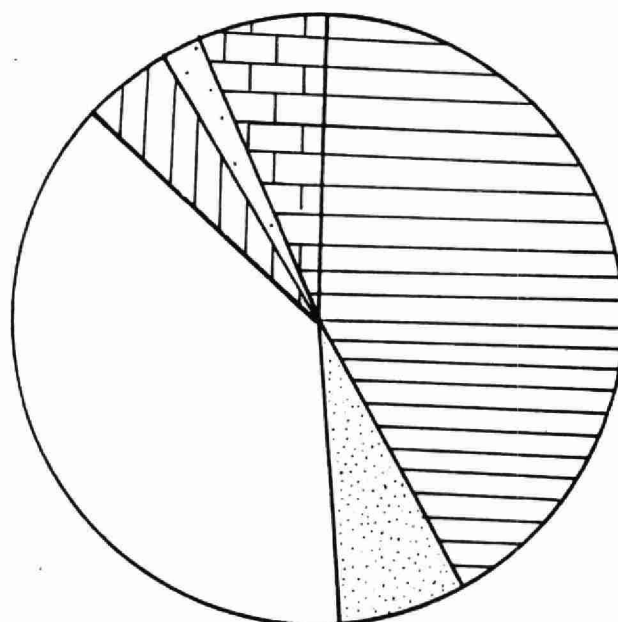


PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

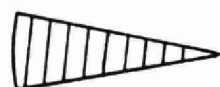
ELLIOT LAKE 1981



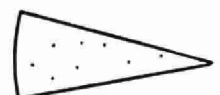
STATION 1



STATION 2



Cyanophyceae



Cryptophyceae



Dinophyceae



Chrysophyceae

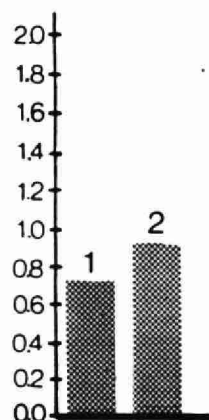


Bacillariophyceae



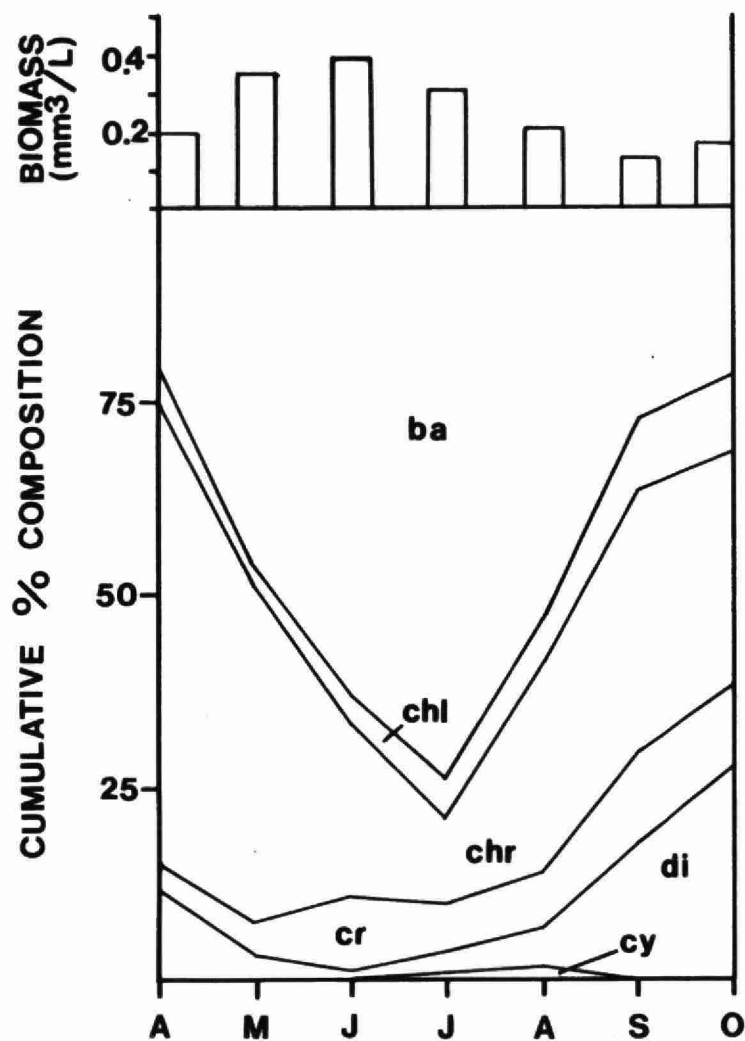
Chlorophyceae

Phytoplankton
Biomass mm^3/L

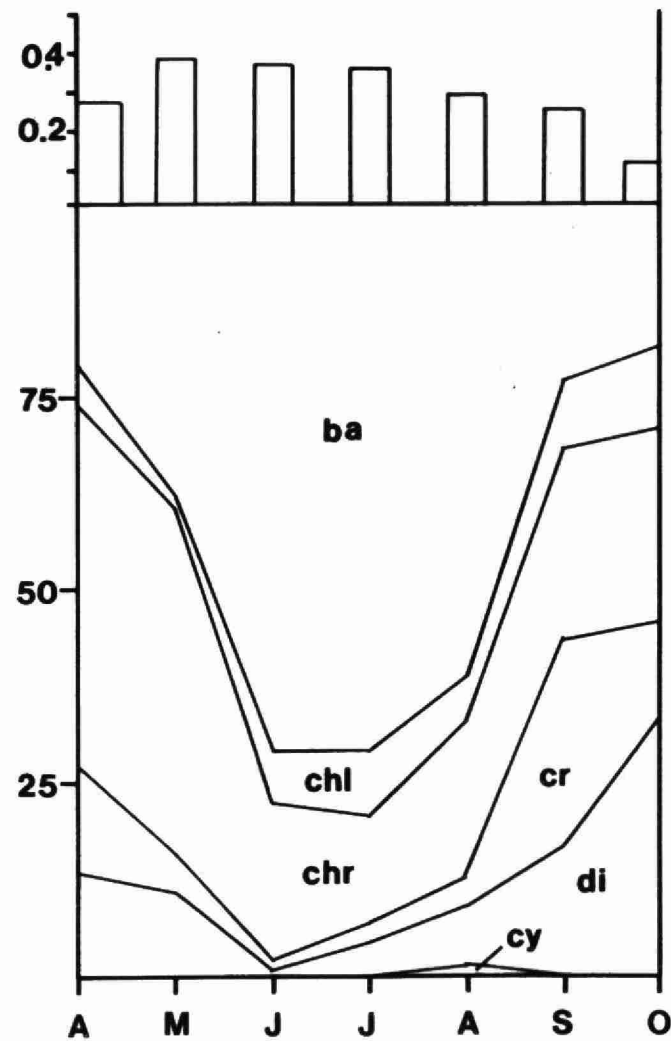


MONTHLY CUMULATIVE PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

NORDIC LAKE 1981



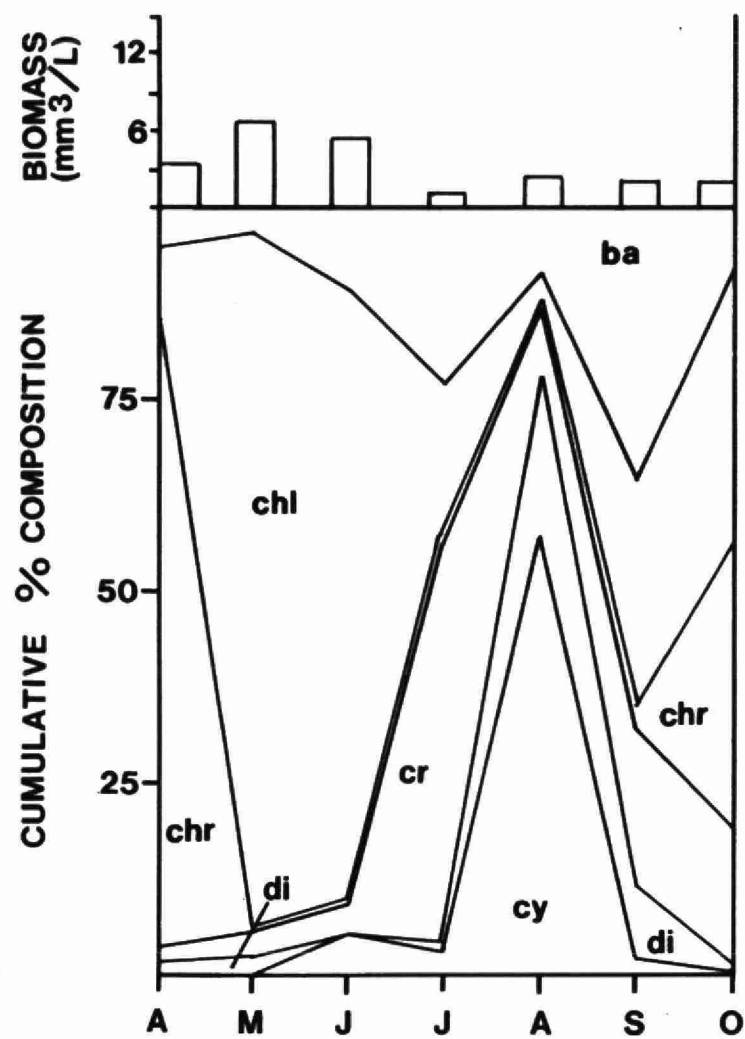
STATION 1



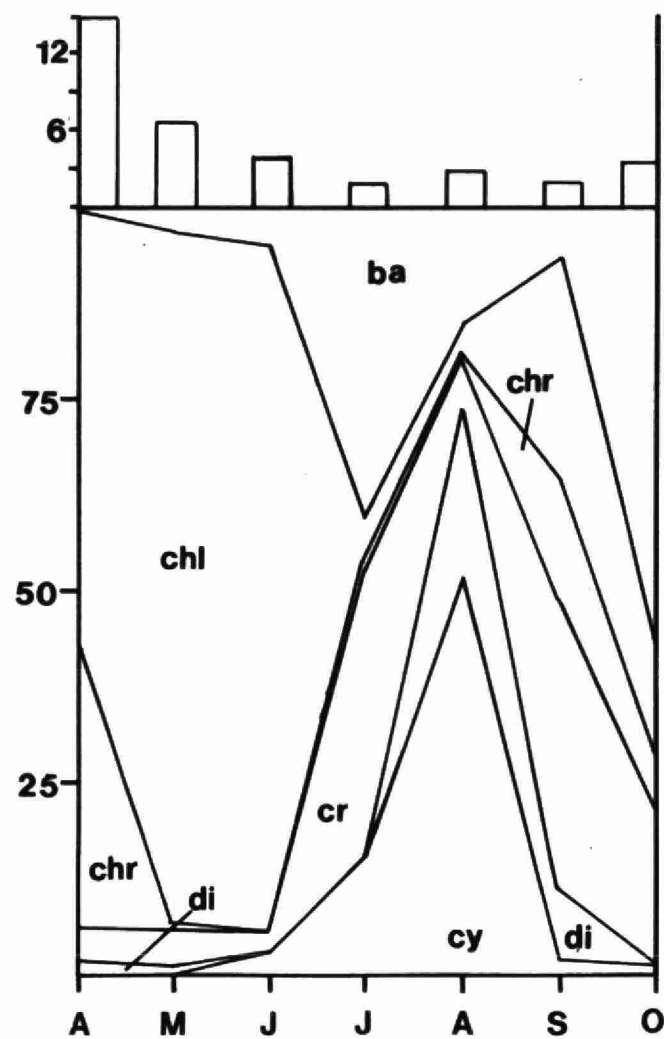
STATION 2

MONTHLY CUMULATIVE PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

ESTEN LAKE 1981



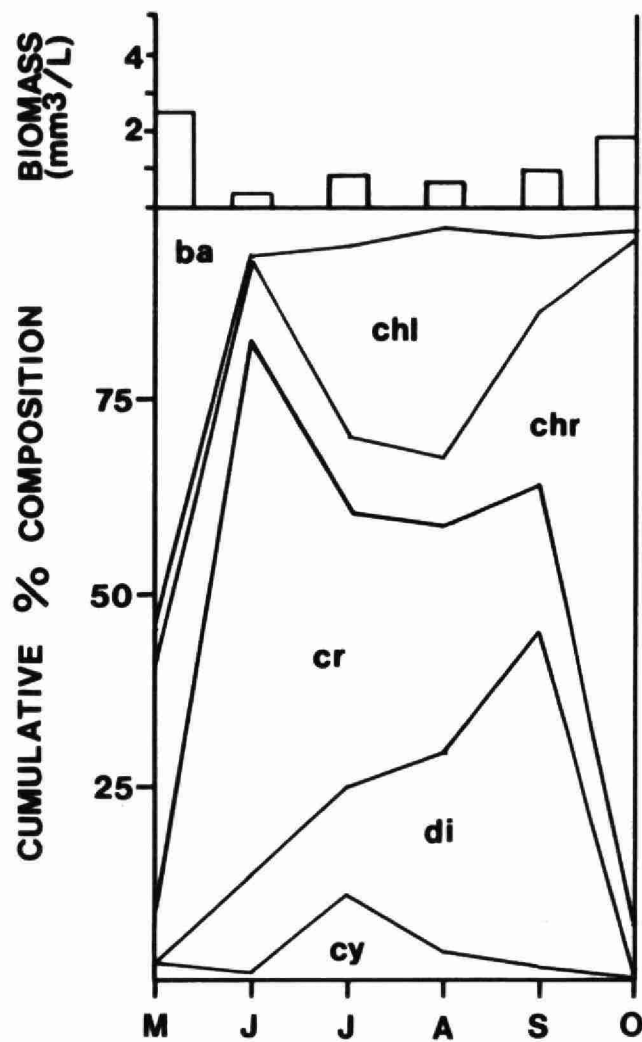
STATION 1



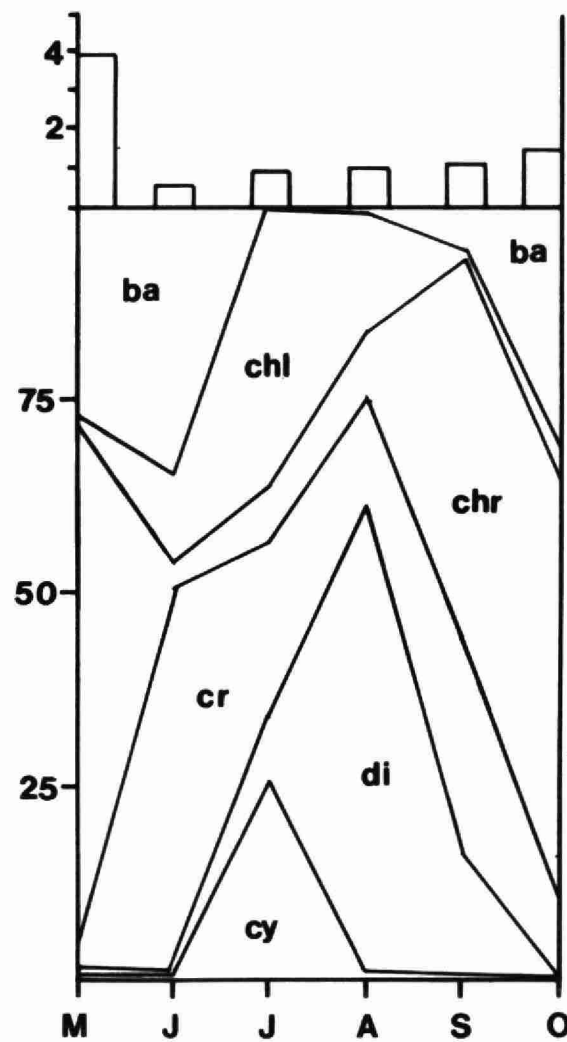
STATION 2

MONTHLY CUMULATIVE PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

DEPOT LAKE 1981



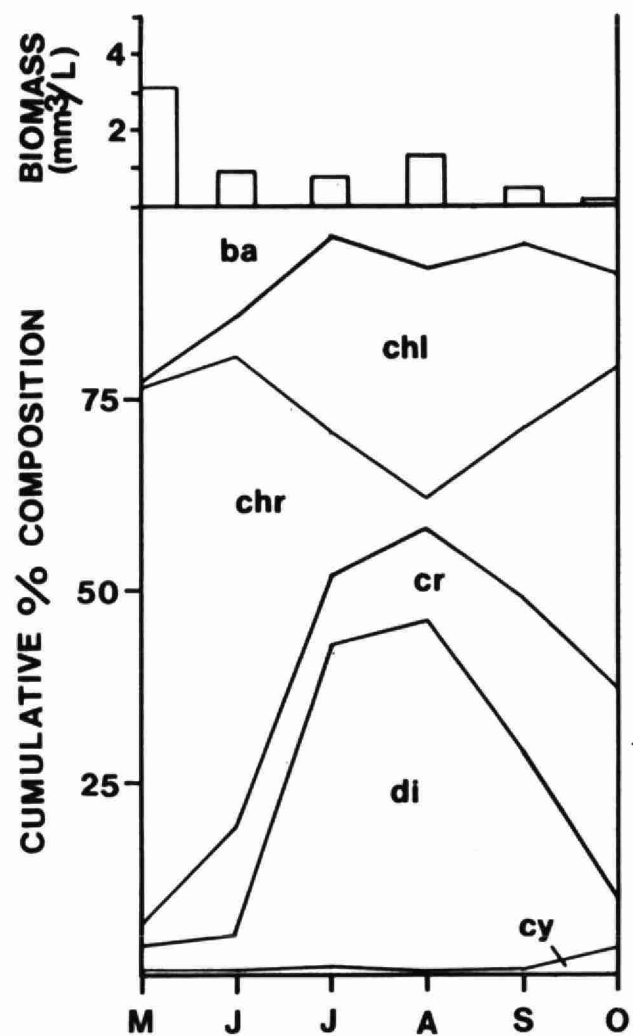
STATION 1



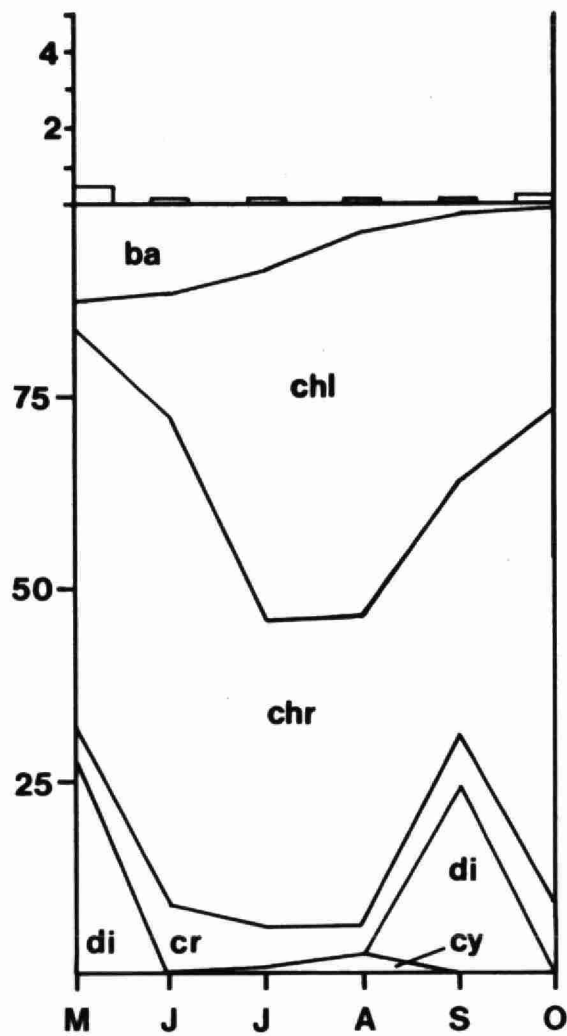
STATION 2

MONTHLY CUMULATIVE PERCENTAGE COMPOSITION OF PLANKTONIC ALGAE BY CLASS

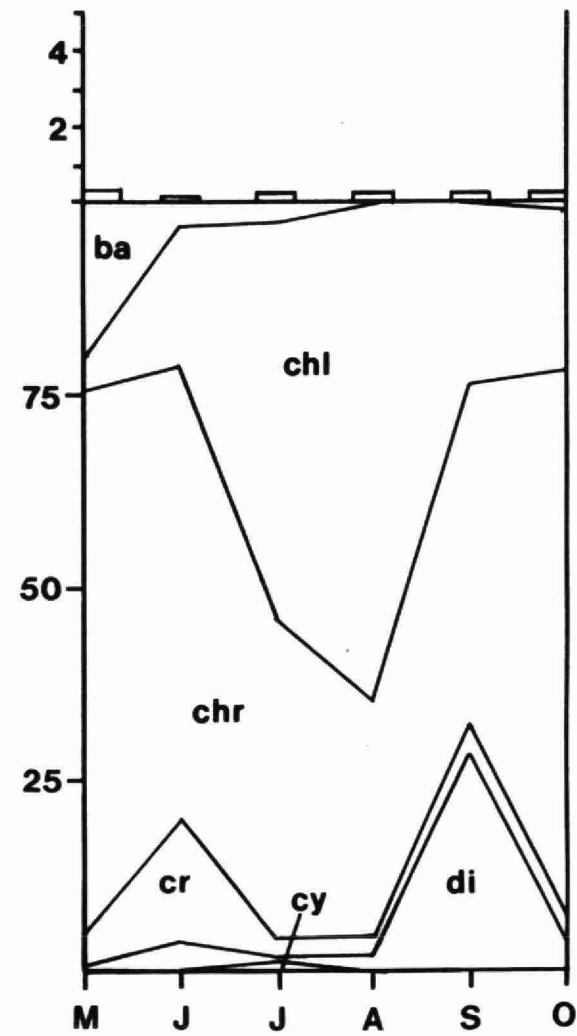
McCARTHY LAKE 1981



STATION 1



STATION 2



STATION 3

Table Ice Free Mean Monthly estimates of zooplankton numbers and biomass ($\mu\text{g}/\text{m}^3$) for six lakes in the south Serpent River watershed, 1981.

	Elliot				Esten			
	#	1 biomass	#	2 biomass	#	1 biomass	#	2 biomass
CLADOCERA								
Eubosmina longispina	36	19	102	55				
E. coregoni	47	103	110	242	64	141	166	365
E. tubicen								
Daphnia longiremis	315	1575	271	1355	129	645	186	930
D. ambigua	87	261	91	273			17	51
D. galeata mendotae	461	4038	355	3110	168	1472	598	5238
D. catawba	7	28	12	48				
D. dubia			8	36				
D. retrocurva							3	9
Bosmina longirostria	77	42	80	43	91	49	166	90
Chydorus sphaericus	86	77	82	74	7	6	7	6
Polyphemus pediculus			3	84				
Leptodora kindtii			5	74				
Holopedium gibberum	117	1280	170	1860				
Diaphanosoma birgei	5	9						
Simocephalus serrulatus								
COPEPODA								
Cyclops scutifer	97	623	54	347	14	90	23	148
C. vernalis			5	16				
C. bicuspidatus thomasi	582	1886	153	496	159	515	611	1980
Diaptomus minutus	570	1140	338	676	2	4		
D. oregonensis	19	67	21	75			3	11
Mesocyclops edax	29	228	76	598	10	79	36	283
Epichura lacustris	28	445	9	143				
Tropocyclops prasinus mexicanus	5	4	12	10	3	3	3	3
Diaptomus sicilis					5	69	20	274
Calanoid copepodids	776	675	1242	1081	46	40	206	179
Cyclopoida copepodids	2332	3498	2104	3156	507	761	876	1314
Nauplii	6298	693	3487	384	846	93	640	70
Rotifer Index*	2		2		3		2	
Total #spp	17		20		11		13	
Total # organisms /m ³ or biomass (mg/m ³)	11974	16.7	8790	14.2	2051	4.0	3561	11.0

*abundance on a scale 1 → 5 (sparse → dense)

Table (continued) Ice Free Mean Montly estimates of zooplankton number and biomass ($\mu\text{g}/\text{m}^3$) for six lakes in the sout Serpent River watershed, 1981.

	Depot				Nordic			
	#	1 biomass	#	2 biomass	#	1 biomass	#	2 biomass
CLADOCERA								
Eubosmina longispina								
E. coregoni	374	823	315	693			1	2
E. tubicen								
Daphnia longiremis	1300	6500	1260	6300	18	90	44	220
D. ambigua	33	99	27	81			1	3
D. galeata mendotae	496	4345	185	1621	200	1752	43	377
D. catawba								
D. dubia								
D. retrocurva					1	3	3	9
Bosmina longirostria	170	92	137	74	796	430	237	128
Chydorus sphaericus			7	6	3	3		
Polyphemus pediculus								
Leptodora kindtii								
Holopedium gibberum	8	88	7	77				
Diaphanosoma birgei								
Simocephalus serrulatus								
COPEPODA								
Cyclops scutifer	24	154	7	45				
C. vernalis								
C. bicuspidatus thomasi	220	713	178	577	6	19	25	81
Diaptomus minutus	24	48	27	54	98	196	31	62
D. oregonensis	20	71	17	60				
Mesocyclops edax	69	543	21	165			1	8
Epichura lacustris							1	16
Tropocyclops prasinus mexicanus	8	7						
Diaptomus sicilis								
Calapoid copepodids	317	276	185	161	324	282	132	115
Cyclopoida copepodids	2601	3902	3397	5096	530	795	328	492
Nauplii	1325	146	2329	256	678	75	718	79
Rotifer Index*	2		2		2		2	
Total #ssp	12		12		7		10	
Total # organisms /m ³ or biomass (mg/m ³)	6989	17.8	8099	15.3	2655	3.6	1564	1.6

*abundance on a scale 1 → 5 (sparse → dense)

Table (continued) Ice Free Mean Monthly estimates of zooplankton numbers and biomass ($\mu\text{g}/\text{m}^3$) for six lakes in the south Serpent River watershed, 1981.

	Un-named 1		1		McCarthy 2		3	
	#	biomass	#	biomass	#	biomass	#	biomass
CLADOCERA								
Eubosmina longispina								
E. coregoni			100	220	36	79	20	44
E. tubicen					2	1		
Daphnia longiremis	422	2110	104	520	13	65	50	250
D. ambigua			4	12	2	6	1	3
D. galeata mendotae	959	8400	4	35	2	18	3	26
D. catawba								
D. dubia					2	9	7	32
D. retrocurva	11	35	105	330	56	176	5	16
Bosmina longirostris	2442	1319	2759	1490			115	62
Chydorus sphaericus	6	5	1	1				
Polyphemus pediculus								
Leptodora kindtii	6	89			1	15		
Holopedium gibberum			44	481	29	317	14	153
Diaphanosoma birgei			66	125	6	11	1	2
Simocephalus serrulatus	3	24						
COPEPODA								
Cyclops scutifer								
C. vernalis					5	16		
C. bicuspidatus thomasi	51	165	227	735	34	110	19	62
Diaptomus minutus	54	108	61	122	29	58	48	96
D. oregonensis	46	163	22	78	3	11	1	4
Mesocyclops edax	9	71	31	244	1	8	1	8
Epichura lacustris	11	175			2	32	1	16
Tropocyclops prasinus mexicanus			31	27			3	3
Diaptomus sicilis								
Calanoid copepodids	205	178	70	61	226	197	121	105
Cyclopoida copepodids	1210	1815	2270	3405	353	530	428	642
Nauplii	1244	137	1303	143	299	33	323	36
Rotifer Index*	2		2		2		2	
Total #ssp	12		14		16		15	
Total # organisms /m ³ or biomass (mg/m ³)	6679	14.8	7202	8.0	1101	1.7	1161	1.6

*abundance on a scale 1 → 5 (sparse → dense)

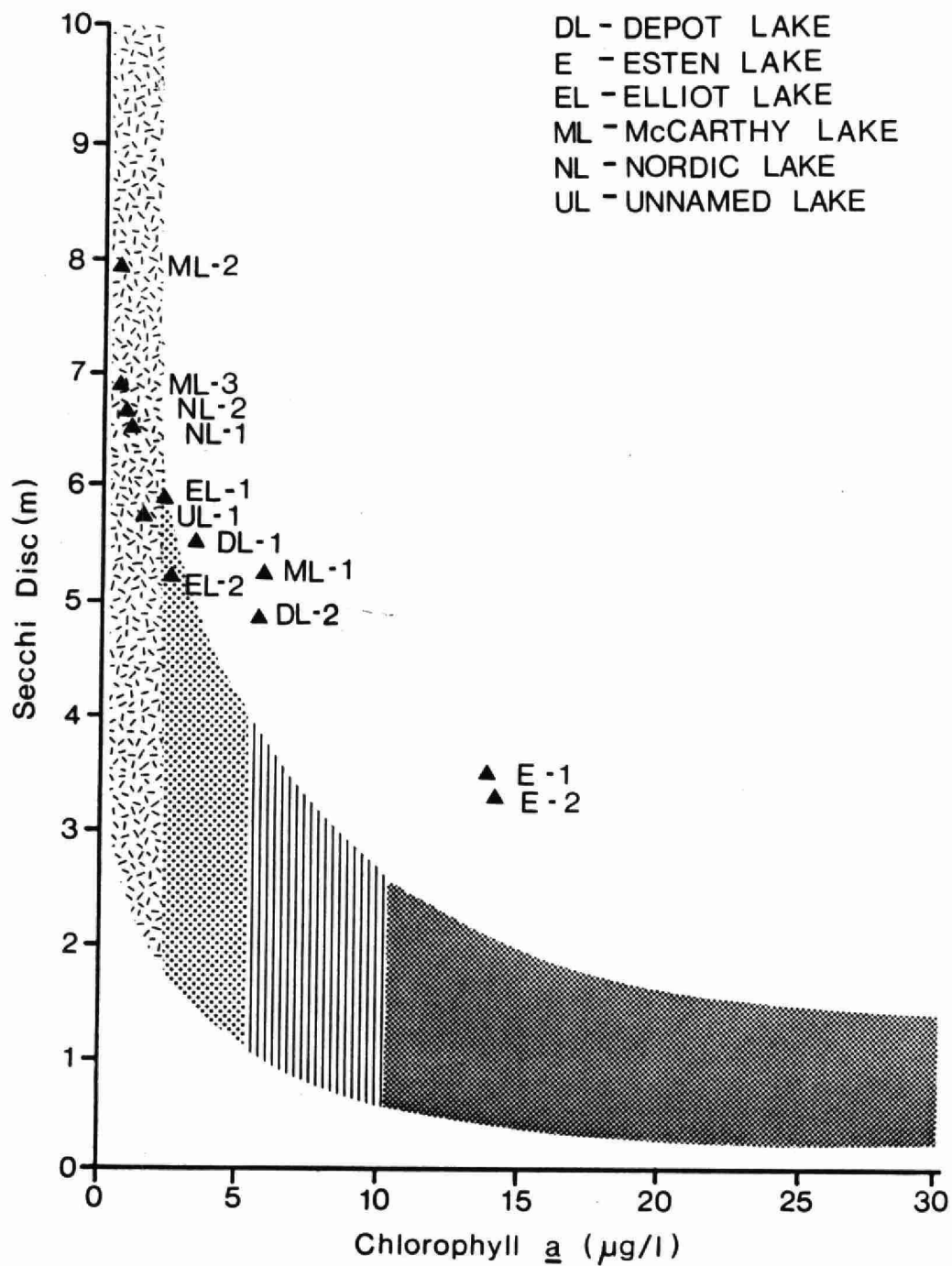
ELLIOT LAKE BENTHOS DATA, 1981

	Elliot Lake		Esten Lake		Nordic Lake		Unnamed Lake	Depot Lake		McCarthy Lake		
	Stn#1	Stn#2	Stn#1	Stn#2	Stn#1	Stn#2	Stn#1	Stn#1	Stn#2	Stn#1	Stn#2	Stn#3
JUNE												
CHIRONIMIDAE												
Chironomus	2	1			60		3				4	8
Cryptochironomus											1	2
CULICIDAE												
Chaoborus								4	2	2	2	
WORMS												
Rhyacodrilus coccineus												2
Limnodrilus												
claparedeianus	65											
Immature h.s.a.*	36	18										
Total Number Organisms	103	19	-	-	60	-	3	4	2	2	7	12
Total Number Taxa	2	2	-	-	1	-	1	1	1	1	3	3
Number Organisms/m ²	915	169	-	-	533	-	27	36	18	18	62	106
SEPTEMBER												
CHIRONIMIDAE												
Chironomus	17	2			26		1				3	10
Tribelos		17			12							1
Procladius	1	2								1	1	1
CULICIDAE												
Chaoborus							3	14	26	400	7	3
WORMS												
Rhyacodrilus coccineus		3										23
Limnodrilus												
claparedeianus	94									1		
Immature h.s.a.*	159	7								3		
Total Number Organisms	271	31	-	-	38	-	4	14	26	405	11	38
Total Number Taxa	3	4	-	-	2	-	2	1	1	3	3	5
Number Organisms/m ²	2406	275	-	-	337	-	36	124	231	3596	98	337

* h.s.a.: hair setae absent N.B. Samples are a pool of 5, 6x6 Ponar dredges

APPENDIX IV

SECCHI DISC - CHLOROPHYLL A RELATIONSHIP
SERPENT RIVER STUDY AREA, 1981



SECCHI DISC - CHLOROPHYLL a RELATIONSHIP
SERPENT RIVER STUDY AREA, 1981

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